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Color Difference and Acrylamide Content of Cooked Food

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Abstract: To investigate the relation between browning color and Acrylamide (AA) content of cooked foods, commercially roasted cereals (barley and corn) were purchased from local markets and French fries and *yakwa* (a traditional Korean fried wheat flour dough) were prepared at the laboratory as a model system. Roasted barley powder for tea bags had the darkest color, whereas roasted barley kernels contained highest amount of AA. There was no significant (at $p<0.01$) correlation between the color difference and the amount of AA in market-purchased roasted cereals. However, when there were equal raw materials and the same recipe was used at the model system there was a highly significant ($p<0.0001$) correlation between color difference and AA content. Both frying time and temperature significantly affected AA content and color. The addition of reducing sugar to *yakwa* did not increase the AA content but was mainly involved in the browning reaction. The above results indicate that the color change due to the browning reaction of market-purchased roasted cereals cannot be an indicator of AA content and the recipe, processing conditions and raw materials should be controlled to compare the relation between color difference and the amount of AA in fried or roasted food.

Key words: Acrylamide, color, roasted barley, roasted corn, French fries

INTRODUCTION

Ever since Acrylamide (AA) was detected in foods, the chemical mechanism for its synthesis in food has been studied. Among the many hypotheses for AA formation, the Maillard browning reaction involving free amino acids and reducing sugars under high temperature has received much attention (Mottram *et al*., 2002; Stadler *et al*., 2002; 2004). Relevant variables and parameters influencing AA formation processing have been considered (Pedreschi *et al*., 2004; Trystram, 2004; Matthaus *et al*., 2004; Levine and Smith, 2005) and raw materials containing asparagines have been proposed as a major factor influencing the formation of AA by the Maillard reaction (Mottram *et al*., 2002; Stadler *et al*., 2002; Yaylayan *et al*., 2003; Stadler *et al*., 2004; Ehling and Shibamoto, 2005). The browning color of food has also been considered as a parameter of AA content (Levine and Smith, 2005). A clear correlation between AA formation and browning color was obtained from the model system of asparagines and glucose (Ehling and Shibamoto, 2005), yeast-leavened wheat bread (Surdyk *et al*., 2004), rye crispbread (Mustafa *et al*., 2005) and potato chips (Pedreschi *et al*., 2005). However, the addition of asparagines increased AA content but did not affect color (Surdyk *et al*., 2004; Ehling and Shibamoto, 2005).

Many studies (Surdyk *et al*., 2004; Levine and Smith, 2005; Ehling and Shibamoto, 2005; Mustafa *et al*., 2005; Pedreschi *et al*., 2005) have found a correlation between browning color and AA formation in laboratory-processed food products. However, although commercial roasted food products, with their browning color and roasting flavor, are very popular in Korea, they have not been studied. Therefore, the aim of this study was to investigate the relation between color difference and

AA content of market-purchased roasted cereals and French fries and *yakwa* (traditional Korean fried wheat flour dough mixed with honey) processed with a standard recipe and controlled cooking conditions.

MATERIALS AND METHODS

Materials

Different brands of roasted barley and corn were purchased at the local market from November 2003 to May 2004. Raw potatoes (Sun-nong, Young Wall, Korea), wheat flour (soft wheat, Baksul Pyo, Seoul, Korea), honey (Dong Suh, Seoul, Korea), corn syrup (corn starch, over 55% maltose, Haechandle, Seoul, Korea), sesame oil (100% sesame, Haepyo, Seoul, Korea) and frying oil (100% soybean, Baksul Pyo, Seoul, Korea) were also purchased at the local market. French fries and *yakwa* were prepared at the laboratory as described in previous research (Koh, 2006).

Determination of Color Difference and Acrylamide Content

Color was monitored using a chromometer (CM-3500D, Minolta Co., Osaka, Japan, calibrated at L = 98.7). L, a and b are chromaticity coordinates, where L = the lightness of the color, positive a = red, negative a = green, positive b = yellow and negative b = blue. Three readings (L, a and b) were taken of the surface of each sample in five replicates. French fries and *yakwa* were cooled to room temperature for 2 h and then the color was measured. The AA content was determined and reported at the previous research (Koh, 2006).

Statistical Analyses of Data

All statistical analyses were performed using the SAS version 8.02 (SAS, 1990). Pearson correlation coefficient analysis was used to investigate the relation between AA content and the color difference of the samples. Generalized Linear Model (GLM) analysis was conducted to analyze the effect of each cooking factor on the amount of AA and the color of the French fries.

RESULTS AND DISCUSSION

The data on AA contents have been cited in a previous report (Koh, 2006) to investigate the relation between color difference and AA content. Compared with roasted barley kernels, roasted barley powder for tea bags had lower Lightness (L) and AA content. For the roasted corn, a similar pattern was observed (Table 1). That is, tea bag products of both corn and barley had darker colors (low lightness and high yellowness) and lower AA contents than did the roasted whole kernel products.

The experiment was chosen to test the effect of frying time and frying temperature on AA content and color difference. The lower and upper levels in the experiment were 160 °C for 4 min and 190°C for 8 min, respectively (Table 2). At the lowest temperature and shortest cooking time, a small amount of AA (73.64 μg kg^{-1}) was detected and the highest AA content (2610.31 μg kg^{-1}) was found in the French fries fried at 190°C for 8 min. As the frying time and temperature increased, both AA content and browning color increased. Lightness (L) was decreased and redness (a) and yellowness (b) was increased. Pedreschi *et al.* (2005) also observed a linear correlation between AA content and color in potato chips.

All experimental *yakwa* were of acceptable eating quality, but the surface color varied from rather light to dark after the addition of reducing sugar (Table 3). The sugar-added *yakwa* I and II were fried at the lower temperature and shorter time and the color changed significantly and the amount of AA was lower. *Yakwa* III, which did not contain sugar, was fried longer to develop a brown color and it

Table 1: Color difference of roasted barley and corn

Products	Brand	L	a	b	AA (μg kg^{-1})
Raw barley		76.40±0.91	2.28±0.12	13.99±0.60	7.41
Roasted barley kernel					
	S	52.15±1.59	6.10±0.23	16.21±0.45	379.65
	B	56.72±0.69	5.89±0.11	17.45±0.39	349.10
	Y	55.70±0.70	6.17±0.10	18.18±0.57	354.28
	H	55.80±0.56	5.64±0.13	16.28±0.51	280.81
	M	58.72±0.59	6.20±0.12	18.55±0.51	327.16
	Mean	55.82±8.70	6.00±1.53	17.33±1.67	338.20±37.12
Roasted barley powder of tea bag					
	D	49.44±0.86	6.47±0.19	15.00±0.67	367.49
	H	47.51±0.84	6.37±0.19	14.28±0.86	165.04
	S	50.08±0.73	6.02±0.16	15.49±0.48	449.15
	Mean	49.01±1.33	6.29±0.24	14.92±0.61	327.23±146.12
Raw corn		90.12±0.51	-0.24±0.04	12.22±0.27	ND
Roasted corn kernel					
	D	67.35±0.75	6.92±0.09	26.84±0.41	392.00
	B	60.32±0.51	7.71±0.17	23.18±0.89	273.97
	H	62.36±1.25	7.57±0.39	23.72±1.39	301.49
	G	61.40±1.08	8.17±0.18	24.39±0.57	245.02
	B	66.00±0.82	7.03±0.21	24.19±0.90	400.30
	Mean	63.49±3.04	7.48±0.51	24.46±1.41	322.56±70.15
Roasted corn powder of tea bag					
	S	61.57±0.61	7.80±0.10	23.90±0.34	115.99
	H	56.98±0.73	7.74±0.26	20.48±0.76	219.14
	D	54.53±0.97	7.42±0.32	19.45±0.93	189.77
	Mean	57.69±3.57	7.65±0.20	21.28±2.32	174.97±53.14

L: lightness, a: redness, b: yellowness; L, a and b-values are mean±standard deviation of five replicates. ND: Not Detectable

Table 2: Color difference of French fries

Frying time (min)	Frying Temp. (°C)	L	a	b	AA (μg kg^{-1})
4	160	53.6±3.88	-5.74±1.4	11.20±3.26	73.64
	170	54.38±2.47	-4.73± 0.86	13.71±2.48	155.57
	180	52.05±4.16	-2.76±1.69	15.67±3.60	502.52
	190	47.15±4.02	-0.16 ±1.77	19.34±3.43	999.90
6	160	53.45±4.06	-5.14±1.10	13.54±2.41	179.63
	170	50.09±3.02	-1.54±1.76	16.79±3.53	435.47
	180	48.05±2.38	-0.39±1.24	19.89±3.19	1097.54
	190	44.51±7.12	3.21±2.06	25.21±4.91	1764.00
8	160	46.06±4.19	-2.79±1.84	13.94±4.46	301.26
	170	50.18±2.39	-1.08±2.00	18.70±4.69	742.94
	180	46.23±3.48	1.81±0.76	22.30±1.99	1938.88
	190	39.95±5.66	3.80±3.59	24.05±4.41	2610.31

L: lightness, a: redness, b: yellowness; L, a and b values are mean ± standard deviation of five replicates

Table 3: Color difference of *yakwa*

Yakwa (frying temp. /time)	L	a	b	AA (μg kg^{-1})
I (140°C /30 min)	43.24±0.92	15.03±0.53	30.44±1.88	57.82
II (140°C /30 min)	40.55±0.95	14.13±0.48	23.68±1.37	135.10
III (140°C /40 min)	58.02±0.55	11.47±0.20	37.75±0.70	294.49

I: Honey added; II: Corn syrup added; III: No sugar added.L: Lightness, a: Redness, b: Yellowness; L, a and b-values are mean±standard deviation of five replicates

contained more AA (294.49 μg kg^{-1}). These results clearly show that, for *yakwa*, reducing sugars, such as honey and corn syrup, are mainly involved in the browning reaction and the frying conditions are more important for the AA content. Surdyk *et al.* (2004) also reported that the addition of fructose was effective in developing brown color, but it did not influence the AA content of yeasted leavened bread.

Table 4: Pearson correlation coefficient (r) of AA contents with color (L, a and b)

	L	a	b
Parameters	r/p-value	r/p-value	r/p-value
Roasted barley	0.15/0.72	-0.13/0.75	0.27/0.51
Roasted corn	0.73/0.04	-0.70/0.05	0.56/0.15
French fries	-0.87/0.0002	0.95/<0.0001	0.93/<0.0001
Yakwa	-0.04/0.96	0.19/0.81	0.75/0.25

L: Lightness, a: Redness, b: Yellowness

Table 5: p-values of GLM analysis of time and temperature of frying and their interaction on AA content and color difference of French fries

Factors	L	a	b	AA
Time	0.0009	0.0002	<0.0001	<0.0001
Temp.	<0.0001	<0.0001	<0.0001	<0.0001
Time × Temp.	0.240	0.255	0.978	<0.0001
Time × Time	0.847	0.659	0.159	0.457
Temp. × Temp.	0.330	0.373	0.851	0.023
R^2	0.721	0.848	0.859	0.965

L: Lightness, a: Redness, b: Yellowness; L, a and b values are mean ± standard deviation of five replicates

Correlation coefficients for AA with L, a and b values were not significant ($p>0.01$) for market-purchased roasted barley and *yakwa*, but were significant ($p<0.001$) for French fries (Table 4). These results indicate that the browning of market-purchased roasted corn and barley cannot be an indicator of AA content because of other influences due to differences in raw materials and cooking conditions on AA content. However, a strong correlation between color difference and AA content was found when the potatoes were fried with the same recipe but with different frying times and temperatures.

GLM analysis of French fries (Table 5) showed the significant effect of temperature and time on color difference and AA content. The interaction between time and temperature was significant for AA content but was not significant for color difference. This linear relation between time and temperature has been found in the other studies (Pedreschi *et al*., 2004; Surdyk *et al*., 2004).

CONCLUSIONS

The significance of the correlation between color difference and AA amount depended on the food. Under the controlled system, the correlation between color difference and the amount of AA was highly significant. However, market-purchased foods did not show a significant correlation between color and AA amount. Even under the controlled system, the addition of reducing sugar enhanced the browning color, but decreased the amount of AA because of the short frying time. Thus, the results indicate that it was hard to estimate the amount of AA from the browning color of roasted food without considering the recipe, processing conditions and raw materials.

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