Measurement of Flour Color in Color Space Parameters

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ABSTRACT

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To adequately describe flour color, brightness and yellowness of flours from 33 crossbred lines of white-grained spring wheat were evaluated. Three tristimulus instruments were compared and, although the range of values differed slightly, they ranked samples in the same order according to either L^* (brightness) or b^* (yellowness). L^* is positively correlated with the Kent-Jones grade value and is negatively correlated with ash content. b^* is positively correlated with the AACC method for extractable yellow pigment. Reflectance measurements could be made on either dry flours or slurries. A flour color index ($L^* - b^*$) determined on dry flour successfully ranked samples in the same order as did visual assessment. This index was more successful than L^*, b^*, Kent-Jones grade value, or yellow pigment value in ranking flours in the same order as the visual assessment.

Flour color became an important commercial factor after the introduction of roller milling. Gradual reduction milling with metal rolls enabled the production of a flour that was whiter and baked better than its predecessors. By consumer demand, color became associated with flour quality (Ferrari and Bailey 1929). William Jago (1895) stated, "[Color] is probably the most difficult and the most important test to be made on flour." Today, color might not be the most important test to be made on flour, but it remains one of the more difficult.

Several workers (Kent-Jones and Herd 1927, Ferrari and Bailey 1929, Yasanuga and Uemura 1962) have recognized that flour color needs to be evaluated by measuring both brightness and yellowness. Brightness, or grade, is affected by bran content and/or extraneous material, whereas yellowness is related to the amount of natural pigments present. The determination of both of these components of flour color has required two analytical procedures. Brightness is usually determined by reflectance of a flour-water slurry using the Kent-Jones color grader (Kent-Jones and Amos 1967) or the Agtron (green) instrument (Gillis 1963, Patton and Dishaw 1968, Shuey 1975). Yellowness is usually determined by colorimetric measurement after solvent extraction of pigments (Kent-Jones and Herd 1927, Markley and Bailey 1935, Fortmann and Joiner 1971).

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The ease with which the Kent-Jones color grader and the Agtron instrument can be used, together with the fact that flour millers are principally interested in grade color as a means of monitoring the performance of their mills, has to a large extent resulted in the yellowness component being ignored. In Australia, usually only the grade value is reported to bakers as an indication of flour color. Bakers require flour with a low degree of yellowness for white breads, and many incorrectly interpret the Kent-Jones grade value (KJ) as a measure of yellowness. KJ is determined at 540 nm, a wavelength chosen deliberately to minimize effects of yellowness (Kent-Jones et al 1950). This wavelength is very close to the wavelength of maximum visibility of the human eye (555 nm) (Croes 1961); therefore, it is an excellent measure of the brightness (blackness or whiteness) of the sample. The carotenoid pigments that contribute to yellowness absorb most strongly around 430 nm (Croes 1961).

The tests of the Kent-Jones color grader and the Agtron measure the reflectance of a flour-water slurry. Slurry formation eliminates particle size differences and aids the detection of bran particles. However, it is the color of dry flour that is usually subjectively assessed by the buyer.

It is important that flour color be correctly defined, measured, and interpreted. Millers are mainly interested in bran contamination. However, with the continuing trend to increased flour extractions, advances in wheat breeding programs have resulted in significant improvements in the extraction levels of new varieties. Measurement of more than mere brightness is imperative. In assessing varietal performance, the flour extraction at the equivalent flour color needs to be compared. In these terms, flour color should be defined as a visible marketing characteristic that includes the attributes of both brightness and yellowness. Mea-

surement of this characteristic should therefore be made on dry flour, rather than on slicks or slurries, in terms imitating visual assessment.

Reflectance spectrophotometers and colorimeters using various tristimulus systems are now readily available and are widely used for color determination in the food and textile industries. These instruments are designed to duplicate the response of the human eye and are based on the definition of standard observer curves adopted by the Commission Internationale de l'Eclairage (CIE) in 1931 and modified in 1964 (Wyszecki and Styles 1982). These instruments offer various color scales, all of which are mathematical transforms of the tristimulus values *X, Y,* and *Z.*

X, Y, and *Z* are measurements of the proportional contributions from the red, green, and blue components of the visible spectra that would match the sample color. The green component of the spectrum is where the human eye is most visually responsive; therefore, the *Y*-tristimulus value can be considered a measure of sample brightness. For a perfect reflecting diffuser, *Y* is equal to exactly 100. A positive difference between the green spectral contribution and the blue spectral contribution indicates yellowness, whereas a negative difference indicates blueness. A positive difference between the red spectral contribution and the green spectral contribution indicates redness, whereas a negative difference indicates greenness. Color can thus be considered in terms of a three-dimensional coordinate system, with brightness from black to white on a vertical scale and a horizontal plane denoting yellow-blueness along one axis and red-greenness along the other.

Unfortunately, the shape described by such a system is not regular, and because the eye is more sensitive to changes in some colors than in others, the comparison of tristimulus values between samples is difficult (Hunter 1975). This problem is overcome by the CIE 1976 (L^*,a^*,b^*) system, which uses cube-root transformations:

$$L^* = 116\,(Y/Y_n)^{1/3} - 16$$
$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$b^* = 200\,[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

X_n, Y_n, and Z_n are the tristimulus values of a nominally white object when illuminated by a standard illuminant, and $Y_n = 100$ by definition.

The values of L^*, a^*, and b^* are therefore dependent on the illuminant source used. D65 is an illuminant accepted as having a spectral radiant power distribution closest to reflected diffuse daylight.

L^* is a function of the green spectral contribution and is a measure of the brightness from black (0) to white (100). a^* is a function of the red-green difference. Positive a^* indicates redness; negative a^* indicates greenness. b^* is a function of the green-blue difference. Positive b^* indicates yellowness; negative b^* indicates blueness. The units within the L^*,a^*,b^* system give equal perception of color difference to a human observer.

Instruments using the L^*,a^*,b^* system with built-in standard illuminants offer the possibility of the simultaneous measurement of all of the color attributes of a flour. In this study, we evaluate three such instruments and describe a procedure for the measurement of dry flour color as distinct from the measurement of flour-water slurry color. Dry flour color and flour-water slurry color have been related to KJ, flour ash content, and the AACC yellow pigment value.

MATERIALS AND METHODS

Three tristimulus machines were compared: a Micromatch 2000 reflectance spectrophotometer (Instrumental Color Systems Ltd., Newbury, UK), a Hunterlab model D25-9SM spectrophotometer (Hunter Associates Laboratory Inc., Reston, VA), and a Minolta chroma meter CR-200 (Minolta Camera Co., Osaka, Japan).

The Micromatch 2000 uses a pulsed xenon lamp with integrating sphere illumination (the desired CIE standard illuminant can be selected), a diode array, and the option of including or excluding the specular component and/or the UV portion of the spectrum. For these experiments, both the specular component and the UV portion of the spectrum were excluded. The Hunterlab D25-9SM uses a halogen incandescent lamp with four solid-state silicon detectors set at 0° viewing angle with the specular component excluded. The Micromatch and the Hunterlab are not portable. The Minolta CR-200 chroma meter is a small portable machine using xenon pulse diffused illumination (only D65 or C standard illuminants are selectable), with three response detectors set at 0° viewing angle and the specular component included. The Micromatch 2000 offers the choice of color matching using either the 2° or 10° standard observer. For these experiments, the 10° observer was selected. Both the Hunterlab D25-9SM and the Minolta CR-200 are preset to use the 2° observer. The 10° observer confers greater precision than the 2° observer.

Thirty-three white-grained spring wheat crossbred lines from the breeding program of the Agricultural Research Institute, Wagga Wagga, NSW, were selected to give a range of grain hardness. Milling through either a Buhler MLU-202 experimental mill (Buhler Bros. Ltd., Uzwil, Switzerland) (9xx sieves) or a Brabender Quadrumat Junior Mark II mill (6xx sieves) (Brabender Ltd., Duisberg, Germany) gave a range of visual color from white to cream. In addition, 10 flour samples obtained from commercial millings of Australian white-grained wheat grists were evaluated.

The color of the dry flour samples was measured in CIE 1976 L^*,a^*,b^* color space. Sample presentation to each machine was in an near-infrared spectrophotometer (NIRS) cup. They were found to be ideal to provide uniform sample presentation to the color meters evaluated. For the Micromatch 2000 and Minolta CR-200, a Technicon IAA NIRS cell (Bran & Luebbe, Nordenstadt, Germany), 35 mm in diameter and 6 mm in depth, was used. For the Hunterlab D25-9SM, a Neotec GQA NIRS cell (NIRS Systems, Pacific Springs, CO), 50 mm in diameter and 10 mm in depth, was used.

Kent-Jones color grade measurements were made in a Kent-Jones and Martin series 3 color grader (Henry Simon Ltd, Stockport, England) by using 30 g of flour plus 50 ml of distilled water, mixing for 45 sec, and reading after an additional 45 sec in a Kent-Jones test cell (Kent-Jones et al 1956). L^*,a^*,b^* measurements of such slurries were made with the Micromatch and Minolta instruments using the Kent-Jones and Martin test cell.

Ash and yellow pigment content were determined by AACC methods 08-01 and 14-50, respectively (AACC 1983). Protein measurements were performed using a Technicon Infra-analyser 400 (Bran & Leubbe) calibrated against Kjeldahl procedure (method 46-12; AACC 1983), and measurements were reported as percent N × 5.7. Grain hardness was determined as pearling resistance by the method of Chesterfield (1971).

Water absorption was measured in the Brabender Farinograph by the official method of the Royal Australian Chemical Institute Cereal Chemistry Division (RACI 1988).

Flour color index (FCI) is defined as $L^* - b^*$.

Statistical analysis for linear or multiple correlation was performed using Genstat IV (Laws Agricultural Trust, Rothamstead, UK). Statistical analysis of ranks was performed using Kramer's rank sum test and Spearman's coefficient of rank correlation (Bender et al 1982).

RESULTS AND DISCUSSION

Comparison of Instruments

The magnitude, values, and range of results produced by the different machines varied. Table I shows the range of values for each instrument and each parameter. On the basis of testing a wide range of commercial and experimentally milled flours not considered in this article, the ranges obtained by the test set studied are representative of flour colors frequently encountered. Table II shows the coefficients of determination relating the three machines.

For the L^* (brightness) values, the Minolta readings were only slightly lower than those of the Hunterlab. The Micromatch was less discriminating, possibly because of the more intense xenon

flash penetrating farther into the layer of flour used in the test cell and resulting in a reduced background-hide effect. The high coefficients of determination between machines indicates that all instruments ranked the samples similarly.

For the a^* (red-green) values, the range from each instrument was very narrow, close to zero, and of a slightly different magnitude. Coefficients of determination between machines were low, indicating that samples were being ranked differently. a^* does not appear to be a particularly useful parameter for color measurement of flour milled from white-grained wheats. It may be more important when red- or purple-grained varieties are considered.

For the b^* (yellow-blue) values, the range, magnitude, and ranking of samples were similar for each instrument. Positive b^* values were obtained from all flours indicating a yellow tint.

The results of the comparison of these three instruments indicate that although the range of values differed slightly, they ranked samples in the same order according to L^* or b^*, and any one of the instruments would be suitable for flour color measurement. Coefficients of determination between instruments were high. In spaghetti measurement, the problem of differences between instruments has been overcome by providing a color map for each type of spectrophotometer used (Walsh et al 1969).

Relationship between KJ, Flour Ash, and CIE 1976 L^*,a^*,b^* Color Space Parameters

Coefficients of determination between KJ and the color space parameters for dry flours and flour-water slurries are listed in Table III.

The strong relationship of KJ with L^* values in both dry flour and flour-water slurries, and the poor relationship with the a^* and b^* values, further indicates that the Kent-Jones color grader principally measures attributes of brightness rather than chroma. However, chroma differences between samples do contribute to the prediction of KJ by color space coordinates.

The variance accounted for by a linear correlation between KJ and L^* was improved from 71.0 to 80.9% by a multiple correlation between KJ and the dry flour color space parameters ($KJ = 65.2 - 0.7L^* + 0.1a^* - 0.3b^*$). On the other hand, the variance accounted for in a correlation between KJ and L^*_{slurry} (95.4) was not improved by a similar multiple correlation that included a^*_{slurry} and b^*_{slurry}. This implies that the factors that contribute to the chroma in the dry flour are transformed in the presence of water to influence the brightness of the slurry. This may well be related to the inherent endosperm grayness factor described by Barnes (1986).

TABLE I
Means, Ranges, and Standard Deviations of Parameters Measured on 33 White Spring Wheat Cultivars

Parameter	Minimum	Mean	Maximum	SD[a]
Micromatch 2000				
L^*	90.00	90.60	91.75	0.39
a^*	0.20	0.42	0.55	0.09
b^*	60.80	8.80	11.00	0.73
Hunterlab D25-9SM				
L^*	90.95	91.73	92.95	0.47
a^*	−0.55	0.01	0.35	0.12
b^*	6.95	8.58	10.80	0.82
Minolta CR 200				
L^*	90.35	91.33	92.55	0.48
a^*	−2.00	−1.64	−1.30	0.12
b^*	6.44	8.25	11.00	0.78
Hardness, g/10 g	3.5	4.0	4.4	0.3
Protein,[b] %	11.9	13.6	15.0	0.6
Kent-Jones color grade	−1.5	−0.4	0.9	0.6
Ash, %	0.36	0.47	0.58	0.07
Pigment, mg/kg	2.1	4.8	6.6	0.9

[a] Standard deviation.
[b] N × 5.7.

TABLE II
Coefficients of Determination for the Correlation Between the Hunterlab D25-9SM, the Micromatch 2000, and the Minolta CR 200 Instruments for Each of the Color Space Parameters

Parameter	Hunterlab	Micromatch	Minolta
L^*			
Hunterlab	100		
Micromatch	97.0	100	
Minolta	95.9	96.8	100
a^*			
Hunterlab	100		
Micromatch	15.3	100	
Minolta	28.4	2.1	100
b^*			
Hunterlab	100		
Micromatch	98.7	100	
Minolta	95.7	97.8	100

TABLE III
Coefficients of Determination for Regressions Between Kent-Jones Grade Value and Color Space Parameters

Parameter	Dry Flour	Flour-Water Slurry
L^*	71.0[a]	95.4
a^*	15.4	NC[b]
b^*	NC	6.8
$L^* + a^*$	77.9[a]	95.3[c]
$L^* + b^*$	71.2[a]	95.3[c]
$L^* + a^* + b^*$	80.9[c]	95.3[c]

[a] Significant at the 95% probability level.
[b] No correlation. Percentage of variance exceeded variance of y-variate.
[c] Significant at the 99% probability level.

TABLE IV
Correlation Matrix Between Several Flour and Grain Parameters That Influence Measurements of Flour Color

	KJ[a]	L^*_{slurry}	L^*_{flour}	Ash	WA[b]	HD[c]	Protein
KJ							
L^*_{slurry}	95.4[d]						
L^*_{flour}	71.0[d]	74.5[e]					
Flour ash	89.7[d]	85.0[d]	68.8[e]				
WA	42.0[e]	43.0[e]	45.3[e]	42.8[e]			
HD	37.7[e]	40.2[e]	40.1[e]	38.1[e]	96.1[d]		
Protein	22.6	24.2	15.1	13.3	32.3[e]	31.5	

[a] Kent-Jones grade value.
[b] Water absorption.
[c] Hardness.
[d] Significant at the 99% probability level.
[e] Significant at the 95% probability level.

TABLE V
Coefficients of Determination for Correlations Between Ash and Color Space Parameters

Parameter	Dry Flour	Flour-Water Slurry
L^*	85.0[a]	68.8[a]
a^*	NC[b]	12.2
b^*	3.9	NC
$L^* + a^* + b^*$	83.8[a]	73.7[a]

[a] Significant at the 99% probability level.
[b] No correlation. Percentage of variance exceeded variance of y-variate.

TABLE VI
Coefficients of Determination of the Correlations Between Brightness Measurements, Ash, and Ash + Hardness

	Ash	Ash + Hardness
KJ[a]	89.7[b]	89.4[b]
L^*_{slurry}	85.0[b]	85.0[b]
L^*_{flour}	68.8[c]	70.0[c]

[a] Kent-Jones grade value.
[b] Significant at the 99% probability level.
[c] Significant at the 95% probability level.

The correlation matrix between several analytical parameters is shown in Table IV. Flour ash content mirrors KJ in terms of the relationships with the various color space coordinates. Principally the effect is on brightness. In the case of the dry flour, there is a slight interaction between ash and a^*. The multiple correlation showed a better relationship than L^* alone (Table V). This indicates that the KJ and the L^*_{slurry} are good predictors of flour ash. The elimination of the effect of particle size in slurries reduced the perceived contribution of grain hardness to the relationship (Table VI).

Dry flour L^* is also a good indicator of flour ash. Although the prediction can be improved using a multiple correlation with L^*, a^*, and b^*, the slurry measurements are still better. By including hardness in a multiple regression of L^* with flour ash content, the correlation was slightly improved.

Protein content has been shown to significantly influence the brightness of flour-water slurries. Moss (1971) showed a positive relationship between KJ and flour protein content for a number of varieties. Barnes (1986) demonstrated that the reflectance at 540 nm of an endosperm-water slurry was inversely related to the protein content of the endosperm. Such a protein effect could be expected to have an impact on any relationships between L^* and other parameters. In this study, however, no significant relationship between protein content and $L^*_{dry\ flour}$, L^*_{slurry}, or KJ was found. The standard deviation of the grain protein content (Table I) indicated that the sample set had a narrow distribution, so it was concluded that any influence of protein content was minimized.

This research demonstrates that color space parameters can be used to predict the KJ or flour ash from either the slurry or the dry flour. Although the relationships with dry flour color space parameters are somewhat lower, dry flour measurement has the added advantages of being a fast and nondestructive test.

TABLE VII
Correlation Between Extractable Yellow Pigment (YP) and b^*

b^* Parameter	Correlation with YP
b^*_{flour}	52.2[a]
b^*_{slurry}	76.1[b]
$(L^* + b^*)_{flour}$	70.6[b]
$(L^* + b^*)_{slurry}$	87.3[b]

[a] Significant at the 95% probability level.
[b] Significant at the 99% probability level.

Relationship Between Yellowness and b^*

Extractable yellow pigment can be correlated to both dry flour and slurry b^* measurements (Table VII). The improved correlation with b^*_{slurry} is because of the elimination of scattering due to particle size effects, and because the enhancement of yellowness in the presence of water is greater for some varieties. For example, variety Rosella has a comparatively low b^*_{flour} but a comparatively high b^*_{slurry} (Table VIII).

Multiple correlations that include L^* and b^* increase the variance accounted for, suggesting an interaction between brightness and yellowness. The coefficients for L^* in the equations were negative, indicating an inverse interaction.

Development of a FCI

Color perception depends not only on recognizing the hue but also on judging differences in attributes such as brightness (the extent to which a stimulus appears to emit more or less light) and saturation (the degree to which a chromatic stimulus differs from an achromatic stimulus regardless of their brightnesses). Whiteness is the attribute in which a stimulus appears devoid of hue and grayness, so in relation to whiteness, only brightness and saturation need be considered. Brightness is dominant; hence, L^* is a good first approximation of whiteness. The dominant wavelength of reflectance of most organic white substances such as flour is about 575 nm (MacAdam 1934). The KJ, which is

TABLE VIII
Minolta Chroma Meter Color Space Measurements, Kent-Jones Grade Value, Flour Ash, and Extractable Yellow Pigment Value for Selected Sample[a]

Crossbred Line	Dry Flour			Flour-Water Slurries			KJ[b]	Ash[c]	EYP[d]
	L^*	a^*	b^*	L^*	a^*	b^*			
Banks	91.53	−1.78	8.79	74.01	−1.44	7.74	−0.9	0.40	0.91
WW728	92.30	−1.76	8.53	74.13	−1.50	7.76	−1.1	0.35	0.90
K113	89.75	−1.48	8.82	73.39	−1.44	7.54	0.2	0.53	0.95
M3844	91.96	−1.73	6.88	72.95	−1.58	8.31	0.9	0.53	0.86
M3802	90.85	−1.99	9.40	73.65	−1.48	8.22	−0.4	0.48	1.04
Rosella	92.28	−1.70	8.01	74.15	−1.50	9.98	−0.8	0.46	1.13

[a] The presence of water enhances the b^* reading in some crossbred lines, e.g., Rosella, M3844.
[b] Kent-Jones grade value.
[c] Percent flour ash content.
[d] Extractable yellow pigment in milligrams.

TABLE IX
Visual Ranking of 10 Commercial Flour Samples by Seven Collaborators

Flour	Collaborator							KRS[a]	MRP[b]
	1	2	3	4	5	6	7		
A	7	10	5	7	8	7	8	52	7
B	9	8	8	8	7	8	7	55	8
C	1	1	1	1	1	1	1	7	1
D	4	3	2	3	3	3	3	21	2
E	6	7	10	9	9	9	9	59	9
F	3	4	6	2	2	2	5	24	4
G	2	2	4	4	4	4	2	22	3
H	10	9	9	10	10	10	10	68	10
J	8	6	3	6	6	6	6	41	6
K	5	5	7	5	5	5	5	36	5
R_s[c]	0.90	0.92	0.82	0.95	0.94	0.95	0.98		

[a] Kramer-ranked sum.
[b] Mean-ranked position as determined by the Kramer-ranked sum.
[c] Spearman's coefficient of rank correlation. No collaborator's evaluation differed significantly ($P > 5\%$) from the mean-ranked position.

measured by using a broadband filter having its main transmission at 530 nm (Anonymous 1970), or the Agtron green value, which is measured at 546 nm (Shuey and Skarsaune 1973), predominantly measure whiteness.

To fully describe any color, including white, three values are needed. However, for reporting convenience, a single value index is preferable. Several whiteness indices have been developed for application in various industries (Wyszecki and Styles 1982). However, many of these whiteness indices place a greater emphasis on the b^* values than on the L^* values. This bias is inconsistent with the intention of CIE L^*,a^*,b^* color space, in which a unit change in L^*, a^*, or b^* represents the equivalent of a unit of change as perceived by a human observer. Croes (1959, 1961) developed a simple formula based on the photoelectric tristimulus reflectance measurements from a green, amber, and blue filter and showed that it could be expressed in terms of the standard CIE system and uniform chromaticity scale specifications. Flour is a yellowish white substance, and a^* values of dry flours from the white wheat samples we have examined are very close to zero, have only a very narrow range, and therefore do not appear to contribute significantly to visual chroma. To be consistent with the CIE 1976 L^*,a^*,b^* color space and with the Croes simple formula approach, it is possible to express flour whiteness as the FCI $L^* - b^*$ for the white wheat flour we have examined. When red or purple pigments are present and contribute a significant positive a^* value, a FCI of $L^* - a^* - b^*$ might be used. In cases where a^* is negative, an index of $L^* - \sqrt{a^{*2}} - b^*$ might be necessary to ensure that the absolute value of a^* is subtracted from the brightness value.

This FCI obviates the inconvenience of referring to three color space parameters, maintains an ascending scale as showing an improvement, and gives equal weighting to both brightness and yellowness. It has been our experience that the range of both L^* and b^* is approximately eight units for both parameters ($L^* = 85$–93, $b^* = 7$–15) for most flours or flour streams.

Sample particle size is known to affect diffuse reflectance. Decreasing particle size decreases the apparent spectral path length throughout the sample, resulting in less absorption but more reflectance. The net effect would be measured as an increase in L^*, a decrease in b^*, and therefore an increase in $L^* - b^*$.

To confirm the suitability of $L^* - b^*$ for ranking flours, 10 commercial flours were ranked visually according to perceived whiteness by seven people (Table IX). A mean-ranked list was generated using Kramer's rank sum test, and it was compared with the rankings by color space coordinate measurements made on the dry flour using the Minolta CR-200 chroma meter, by KJ, and by extractable yellow pigment value. Spearman's coefficient of rank correlation shows that, compared with visual examination, the FCI $L^* - b^*$ ranks flours better than L^*, b^*, KJ, or extractable yellow pigment individually (Table X).

TABLE X
Ranked Position of 10 Commercial Flours by Instrumental Measures[a]

	Minolta 200 Chroma Meter Rankings				
Flour	L^*	b^*	$L^* - b^*$	KJ[b]	EYP[c]
A	8 (89.6)	8 (9.9)	8 (79.7)	9 (+2.3)	8 (2.6)
B	6 (89.8)	7 (9.3)	7 (80.5)	3 (−0.4)	7 (2.5)
C	1 (91.9)	1 (4.9)	1 (87.0)	1 (−2.8)	1 (0.8)
D	5 (89.9)	=4 (7.5)	4 (82.4)	=4 (0.7)	3 (1.5)
E	9 (89.3)	10 (10.4)	9 (78.9)	8 (1.9)	10 (2.9)
F	3 (90.2)	2 (7.3)	3 (82.9)	=4 (0.7)	5 (1.8)
G	2 (91.2)	=4 (7.5)	2 (83.7)	2 (−0.8)	4 (1.7)
H	10 (87.9)	9 (10.3)	10 (77.6)	10 (3.8)	9 (2.7)
J	4 (90.0)	6 (8.3)	6 (81.7)	7 (1.6)	6 (2.2)
K	7 (89.7)	3 (7.4)	5 (82.3)	6 (0.9)	2 (1.4)
R_s[d]	0.91	0.90	0.98	0.80[e]	0.76[e]

[a] Actual measurement is given in parentheses.
[b] Kent-Jones color grade.
[c] Extractable yellow pigment value.
[d] Spearman's coefficient of rank correlation.
[e] Significantly different ($P > 5\%$) from the visually assessed mean-ranked position according to Kramer's rank sum (Table IX).

CONCLUSIONS

The tristimulus measurement of flours in CIE 1976 L^*,a^*,b^* color space enables the simultaneous estimation of both the brightness and yellowness components of color. The measurement of flour-water slurries, rather than dry flour, is more highly correlated to the KJ and ash measurements once made traditionally. However, the use of the FCI ($L^* - b^*$) as a single index combination of brightness and yellowness of dry flour more successfully ranked flours similarly to visual assessment rankings. FCI as measured on dry flour has the advantages of being nondestructive, easily measured, and relatable to a perceived appearance attribute.

An important reason for measuring flour color is to anticipate end product color. Neither KJ nor ash content is a good predictor of end product color. Both have been shown to be well related to flour brightness, so presumably flour brightness is not a good measure of end product color. The direct measurement of flour brightness, L^*, or its measurement through the FCI will not confer any advantage in this respect. However, the FCI also incorporates a measure of flour yellowness. If flour yellowness has an impact on end product color, then the FCI will be better able to predict that end product color than KJ, ash, or L^*.

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Influence of Protein Addition on Rheological Properties of Amylose- and Amylopectin-Based Starches in Excess Water

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ABSTRACT

The effect of zein, gliadin, glutelin, and glutenin on the rheological properties of amioca (98% amylopectin) starch, Hylon V (50% amylose and 50% amylopectin), and potato starch (100% amylose) was determined in small-amplitude oscillatory measurements at temperatures ranging from 64 to 100°C. The results showed that starch viscosity was significantly affected by the presence of protein. The amylose-amylopectin ratio, the type of protein, and temperature, coupled with residence time and moisture content, appeared to affect the extent of viscosity change. The gelatinization of amylopectin favored a synergistic increase in viscosity with addition of protein. Gliadin and glutenin resulted in greater increases in viscosity than did zein and glutelin, which are more hydrophobic. The gelatinization of amylose starch did not result in the same type of synergistic interactions.

Although rheological properties of cereal biopolymers such as starch (Greenwood 1979) and protein (Nielson et al 1962, Hamada et al 1982, Inde and Rha 1982) have been studied individually, little work has been done to understand whether the rheology of their mixtures generates synergistic or antagonistic results during cooking. Examples of such work include studies of the frequency dependence of the storage modulus for gluten-starch mixtures, which were shown to become steeper as the protein-starch ratio decreased (Hibberd 1970). Additionally, interactions among different constituents of cereal flours were shown to contribute to the properties of their doughs (Bushuk 1986).

D'Appolonia and Shelton (1984) suggested that there is a considerable amount of indirect evidence that wheat flour proteins interact with varying degrees of specificity with flour carbohydrates when flour is mixed with water to form a dough. For example, they suggested that wheat starch granules have unique surface properties that facilitate interaction with gluten proteins. Baking studies performed by Hoseney et al (1971) showed that starch-gluten doughs made from wheat, barley, and rye behaved similarly to one another, whereas corn, oat, and rice starches behaved differently from one another.

There are no data that report specific interactions between gliadin and starch or glutenin and starch containing various amylose-amylopectin ratios. The same is true for zein and starch and glutelin and starch. The objective of this article is to report studies on the effect of zein, gliadin, glutelin, and glutenin on the rheological properties of a 98% amylopectin starch, a 50% amylose and 50% amylopectin starch hybrid (Hylon V), and potato amylose (100% amylose) as a function of moisture content and temperature as measured by the complex viscosity (η^*) in small-amplitude oscillatory measurements. The results should help elucidate the role of the amylose-amylopectin ratio and type of protein on rheological properties of starch-protein mixtures and determine whether synergistic or antagonistic results are obtained.

MATERIALS AND METHODS

Amioca (98% amylopectin) lot AG42D8, Hylon V (50% amylose and 50% amylopectin starch) lot AG3501, and isolated potato amylose lot KDD26 were donated by the National Starch and Chemical Corporation, Bridgewater, NJ. Zein (lot 84F-0155) was obtained from the Sigma Chemical Company, St. Louis, MO. Glutelin was extracted from corn meal gluten (lot 86F-0074, Sigma) according to the method proposed by Osborne (1907) using 70% ethanol. Gliadin (lot 35F-8160) was obtained from Sigma directly, and glutenin was extracted using Osborne's method from Sigma wheat gluten meal (lot 15F-0182).

Initial moisture content was determined by placing approximately 5 g of each material in a vacuum oven at 100°C with a pressure of approximately 25 mmHg according to AACC method 44-40 (AACC 1983). The protein-starch ratio for each of the protein-starch systems was kept constant at 12 parts of protein to 88 parts starch by weight on a dry basis. This ratio was selected because it represents the average ratio of starch to protein commonly found in flour. Samples were uniformly mixed in the order of protein to starch by dry blending with a mixer and then were added to water to assure homogeneity as well as full hydration of both protein and starch. Samples were allowed to equilibrate and hydrate for 1 hr before experimentation. Estimated total moisture contents of 55, 64, and 82% were used for amylopectin, and total moisture contents of 64, 70, 75, and 82% were used for Hylon V-protein systems. Moisture contents

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