MEASUREMENT OF FLOUR WHITENESS[1]

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ABSTRACT

The whiteness of wheat flour was determined by means of photoelectric tristimulus measurements and substitution of the reflectance values A, B, and G in a newly derived equation for whiteness. This formula, which is in its most simple form $W = G - A + B$, simplifies the calculation of whiteness considerably, and, therefore, should be considered as useful for routine application. The results obtained were in complete accord with the visually estimated orders as found by means of the Pekar test. They can be considered as representative for visual judgments in average daylight.

The whiteness of flour is governed by two independent factors, namely lightness ("brightness") and degree of yellowness (saturation or departure from neutral white).

The lightness is related to the amount of bran content that is present in the flour, but it is also influenced by the granularity (particle size) of the flour. The degree of yellowness is dependent upon the amount of carotene and xanthophyll in the original wheat and the extent to which the flour has undergone natural and artificial bleaching.

The earliest and most widely used method of assessing the color of flour is the Pekar test. Although this visual test undoubtedly is very useful, it does not permit fixation of the results in objective figures. On account of this drawback, attempts have been made to devise methods of evaluating the color of flour and to record the results on a numerical basis. Concerning whiteness most of these methods, however, are limited to the determination of one of the two factors governing whiteness.

The Kent-Jones & Martin Flour Color Grader is a reflectometer, especially designed for the milling industry. It enables the miller to be informed quickly about the proportion of branny matter in the flour, since "color grade" is approximately correlated with degree of extraction. To eliminate the influence of granularity, the flour is made into a smooth paste by mixing together 30 g. of flour and 50 ml. of distilled water. Immediately after mixing, this paste is poured into a glass cell and the amount of light reflected, after passing a green filter, is recorded by means of a photoelectric cell and galvanometer. The

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color grade of the flour is then read off on a scale (4,5,6).

The green filter of the Kent-Jones & Martin Flour Color Grader has its peak transmission at 530 mμ. As maximum visibility for a normal human eye occurs at 555 mμ, this instrument measures the approximate lightness. The lightness is that attribute of a color which permits it to be classed as equivalent to some member of the series of grays ranging from absolute black (zero) to pure white (100). In expressing the visual impression of whiteness, however, the lightness alone is inadequate, since the degree of yellowness should also be taken into account.

Materials and Methods

With a photoelectric tristimulus reflectometer (2) it is possible to determine lightness and degree of yellowness. This instrument is based on the principles of the CIE[3] standard system for designating colors. On the premise that the visual judgments are made in average daylight, it duplicates an observer, in fact the CIE standard observer, by a source-photocell combination with three filters. The only difference in operating procedure from the Kent-Jones & Martin Flour Color Grader is that on each sample three readings instead of one have to be taken. These readings are the reflectance values A, B, and G, obtained by measuring with the amber, blue, and green filter of the tristimulus set. The setting with the tristimulus green filter is identical with lightness in the CIE meaning. The degree of yellowness can be computed from the equation for yellowness as given by Hunter (2): Yellowness = (A − B)/G.

In general, the whiteness increases if the lightness increases or if the degree of yellowness decreases. But, in expressing the visual impression of whiteness, it is necessary to have one figure in which both the positive effect of lightness and the negative effect of yellowness are taken into account. The calculations of whiteness with the formulas mentioned in literature, however, are rather complicated and are, therefore, to be considered as less suitable for use in practice.

Whiteness can be calculated directly and in a simple way by using formula

$$W = G - A + B, \qquad (W')$$

in which A, B, and G are the three tristimulus reflectance values. This formula was derived theoretically from the CIE standard system, taking into account the mentioned equation for yellowness (1).

Formula $W = G - A + B$ was tested in the following way. With a tristimulus reflectometer the reflectance values A, B, and G were

[3] Commission Internationale de l'Eclairage.

determined with a series of six samples of wheat flour of different origin (Table I), six samples of low-grade flour (wheat feed) of different origin (Table II), one sample of flour, bleached with five different quantities of benzoyl peroxide (Table III), and one sample of flour, bleached with five different quantities of chlorine dioxide (Table IV). Whiteness was calculated from the newly derived formula, and also from the equation recommended by Hunter (2) for the calculation of whiteness from data obtained with the tristimulus reflectometer:

$$W = 1 - \left[\left\{ 8.6 \ (a^2 + \beta^2)^{1/2} \right\}^2 + \left\{ \frac{(1.00 - Y)}{2} \right\}^2 \right]^{1/2}, \qquad (W'')$$

in which $a = 2.5 \ (A - G) : 10 \ G$, $\beta = (G - B) : 10 \ G$ and $Y = G$.

This equation was derived by Hunter from the formula suggested by Judd (3):

$$W = 1 - \frac{1}{K} \Delta E_{MgO \text{ to specimen}}$$

Originally K was given the value 20 and in Hunter's formula this value was used. Considering Judd's remark (3), however, that the value of K should be set much higher than 20 if the visual judgments are made on samples with a fine dividing line, the value 70 was chosen as proposed by Selling and Friele (7). In that case the numerical coefficient in Hunter's formula becomes 8.6 instead of 30.

The orders of whiteness were also determined visually by seven persons with the familiar Pekar test for milling products. As the measurements with the tristimulus reflectometer were made on pastes, obtained by stirring 30 g. of flour with 50 ml. of distilled water, the visual estimation was brought in line with them by determining the orders of whiteness on moistened material.

Results and Discussion

In Tables I, II, III, and IV the measured reflectance values (Amber, Green, Blue) are given, as well as the figures for Lightness, Yellowness, and Whiteness (W′, W″) computed from them. For convenience the results obtained by means of Hunter's formula for whiteness (W″) are expressed as a percentage. The orders of lightness, yellowness and whiteness are indicated by means of the figures 1 to 6: 1 = highest degree of lightness, lowest degree of yellowness, or highest degree of whiteness; and 6 = lowest degree of lightness, highest degree of yellowness, or lowest degree of whiteness. For comparison the results of the visual assessments are given in the last column

TABLE I

RESULTS OF TRISTIMULUS MEASUREMENTS ON SIX SAMPLES OF WHEAT FLOUR OF DIFFERENT ORIGIN
(Numbers in parentheses indicate order or sequence)

No.	Material	Reflectance Values[a]			Lightness[b]	Yellowness[c]	W'[d]	W''[d]	Pekar[e]
		Amber	Green	Blue					
1	Patent flour	65.4	64.3	56.8	64.3(2)	0.134(1)	55.7(1)	79.2(1)	1
2	Patent flour	65.7	64.4	56.7	64.4(1)	0.140(2)	55.4(2)	79.0(2)	2
3	Imported flour	65.1	63.6	55.2	63.6(3)	0.156(3)	53.7(3)	78.0(3)	3
4	Imported flour	64.4	62.9	54.5	62.9(4)	0.157(4)	53.0(4)	77.6(4)	4
5	Baker's grade flour	63.8	62.4	53.4	62.4(6)	0.167(5)	52.0(5)	77.0(5)	5
6	Baker's grade flour	63.9	62.5	53.1	62.5(5)	0.173(6)	51.7(6)	76.7(6)	6

[a] Amber, Green, and Blue: respectively, reflectance value with the tristimulus amber, green, and blue filters.
[b] Lightness: G.
[c] Yellowness: $(A - B)/G$.
[d] Whiteness: $W' = G - A + B$. $W'' = 1 - [\{8.6(a^2 + \beta^2)^{1/2}\}^2 + \{(1.00 - Y)/2\}^2]^{1/2}$.
[e] Visual assessment of whiteness by means of the Pekar test on moistened material.

TABLE II

RESULTS OF TRISTIMULUS MEASUREMENTS ON SIX SAMPLES OF LOW-GRADE FLOUR (WHEAT FEED) OF DIFFERENT ORIGIN[a]
(Numbers in parentheses indicate order or sequence)

No.	Material	Reflectance Values			Lightness	Yellowness	W'	W''	Pekar
		Amber	Green	Blue					
1	Low-grade flour	52.1	49.5	35.8	49.5(1)	0.329(1)	33.2(1)	63.5(1)	1
2		50.5	47.9	34.7	47.9(2)	0.330(2)	32.1(2)	62.9(2)	2
3		46.4	43.7	30.7	43.7(4)	0.359(3)	28.0(3)	59.7(3)	3
4		46.1	43.5	30.0	43.5(5)	0.370(5)	27.4(4)	59.1(4)	4
5		45.4	42.5	30.0	42.5(6)	0.362(4)	27.1(5)	59.0(5)	5–6
6		47.7	44.1	30.6	44.1(3)	0.388(6)	27.0(6)	57.8(6)	5–6

[a] See footnotes, Table I.

TABLE III

RESULTS OF TRISTIMULUS MEASUREMENTS ON A SAMPLE OF FLOUR BLEACHED WITH FIVE DIFFERENT QUANTITIES OF BENZOYL PEROXIDE[a]
(Numbers in parentheses indicate order or sequence)

No.	Amount of Bleaching Agent	Reflectance Values			Lightness	Yellowness	W′	W″	Pekar
		Amber	Green	Blue					
	g/100 kg								
1	Blank	59.5	58.1	46.6	58.1(5)	0.222(6)	45.2(6)	72.5(6)	6
2	0.75	59.3	58.0	47.0	58.0(6)	0.212(5)	45.7(5)	73.0(5)	5
3	1.50	59.8	58.3	48.4	58.3(4)	0.196(4)	46.9(4)	73.9(4)	4
4	2.25	59.7	58.5	48.5	58.5(1–2)	0.192(3)	47.3(3)	74.2(3)	3
5	3.00	59.4	58.4	49.1	58.4(3)	0.176(2)	48.1(2)	74.8(2)	2
6	3.75	59.7	58.5	49.7	58.5(1–2)	0.171(1)	48.5(1)	75.2(1)	1

[a] See footnotes, Table I.

TABLE IV

RESULTS OF TRISTIMULUS MEASUREMENTS ON A SAMPLE OF FLOUR BLEACHED WITH FIVE DIFFERENT QUANTITIES OF CHLORINE DIOXIDE[a]
(Numbers in parentheses indicate order or sequence)

No.	Amount of Bleaching Agent	Reflectance Values			Lightness	Yellowness	W′	W″	Pekar
		Amber	Green	Blue					
	mg/kg								
1	Blank	62.3	60.7	49.3	60.7(3)	0.214(6)	47.7(6)	73.9(6)	6
2	10	62.2	60.6	50.7	60.6(4)	0.190(5)	49.1(5)	75.2(5)	5
3	20	62.2	61.0	52.1	61.0(1–2)	0.166(4)	50.9(3)	76.4(4)	3
4	30	62.4	61.0	52.9	61.0(1–2)	0.156(3)	51.5(1)	76.9(1)	1
5	50	62.0	60.4	53.0	60.4(5)	0.149(2)	51.4(2)	76.8(2)	2
6	100	60.6	59.2	52.0	59.2(6)	0.145(1)	50.6(4)	76.5(3)	4

[a] See footnotes, Table I.

(Pekar): 1 = highest degree of whiteness, and 6 = lowest degree of whiteness.

The orders of whiteness, resulting from the calculations with both formulas, were in agreement with the visual assessments by means of the Pekar test, apart from one change of place of two samples in Table IV where Hunter's formula was used.

The orders of lightness are in general very different from the visual arrangements according to Pekar. In Table IV there is a noticeable decrease in lightness in samples 5 and 6, owing to an overdose of chlorine dioxide and also effecting a decrease in whiteness.

The orders of yellowness are in considerably better agreement with the results of the Pekar test, but on the whole the results confirm the fact that, in evaluating a figure for whiteness, both lightness and yellowness must be taken into account.

In Tables III and IV, the effect of bleaching agents can be followed from the calculated figures for yellowness.

The use of formula $W = G - A + B$ means a considerable simplification of the calculation of whiteness and facilitates practical application of the tristimulus method for objective whiteness measurements. The results obtained were in complete accord with the visually estimated orders as found by means of the Pekar test. They can be considered as representative for visual judgments in average daylight.

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