Determination of Oil Color by Image Analysis

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ABSTRACT: An image analysis method was developed to determine oil color based on Lovibond-red according to Chinese standard GB5528-85. For one hue, one feature of image analysis, a negative correlation with the red reading of the Lovibond tintometer ($r > 0.995$) was found. Mathematical models were designed to measure oil color based on image analysis. Forty-nine oil samples including peanut oil, soybean oil, fragrant sesame oil, rapeseed oil and cottonseed oil were evaluated to assess the performance of the image analysis models. Good agreement, $r^2 = 0.999$, between image analysis values and visual color measurement by using the Lovibond Color Scale was obtained.

Paper no. J9621 in *JAOCS 78,* 749–752 (July 2001).

KEY WORDS: Cottonseed oil, fragrant sesame oil, image analysis, Lovibond tintometer, oil color, peanut oil, rapeseed oil, soybean oil, visual color.

Color is an important quality parameter of edible oil, both in the refining process and in the marketplace. It is also frequently monitored in the product line according to some commercial standard in order to maintain a consistent quality. Primarily owing to naturally occurring polyphenolic pigments, gossypol, chlorophyll, carotenoids, and so forth, each oil has its own characteristic color (1). Therefore, oil color is often specified both in the market and in the trade rules established by various associations. For example, peanut oil of the first grade for cooking should not exceed 2 Lovibond red with fixed Lovibond yellow 20 according to Chinese national standard GB5525-85, and peanut oil of the first grade for salad use should be no more than 1.5 Lovibond red with fixed yellow 15 (2).

Lovibond color of oil is the most widely used color measurement in the edible oil industry. It is a visual comparison method in which a colorimeter is used (AOCS) with a set of colored glasses. The Lovibond method, American Oil Chemists' Society (AOCS) (3) Method Cc 13e-92, requires a Model E Lovibond Tintometer and red, yellow, blue, and neutral glasses to match the oil color. This method is practiced primarily outside of the United States and Canada. The Wesson method, published as AOCS official method Cc 13b-45 in 1945, requires the AF710 AOCS Tintometer to match the oil color with red and yellow glasses (3,4). Chinese national standard GB5525-85 requires a Model E Lovibond Tintometer to measure oil color with different fixed yellow readings.

These methods are accurate but require an experienced observer to achieve the desired reliability and repeatability. Although the Lovibond system has served a useful and needed purpose, the technology used in visual colorimeters lags well behind the recent advances in scientific instruments. A collaborative effort in the late 1940s led to the development of an official spectrophotometric color method that showed good correlation with the visual Lovibond method ($r^2 = 0.993$) and is a potential alternative to the manual method (5). However, the spectrophotometric method is seldom used (6,7).

In the early 1990s, Japan developed a KC-560 on-line automated spectrum meter to measure oil color. Red readings measured by this method show good correlation with Lovibond red values, but a large yellow reading error exists between the two methods (8). In 1995 Wan and Pakarinen (9) demonstrated that the Colourscan can provide red color readings of refined and of refined, bleached cottonseed oils with good agreement vs. the values obtained by the visual Tintometer ($r^2 = 0.99$). A broad correlation between an improved version of the Colourscan PFX990 and the visual method was presented in an international collaborative study in the following years (10). ISO 15305:1998(E) specifies that the Lovibond Universal tintometers Model F (BS684) and Model F/C are suitable, and that the older Models AF905 and AF900/C Model E tintometers are suitable but no longer available; the AF710, Lovibond Schofield, Wesson, and AOCS colorimeters are not suitable (11).

The present work was done to assess the feasibility of using a digital image analysis method to determine oil color.

EXPERIMENTAL PROCEDURES

Samples. All oil samples were collected from different areas of Henan province by the Inspection Office of Henan Grain Bureau. There were 49 samples, including 17 peanut oil samples, 5 rapeseed oil samples, 6 cottonseed oil samples, 10 soybean oil samples, and 11 fragrant sesame oil samples. The samples were all commercial grade.

Method. Visual color measurement of 49 samples was determined by three technicians from two laboratories according to Chinese national standard GB5525-85 with a Tintometer Model E AF900 (the Tintometer Ltd.) and a 25.4-mm (1 in.) sample glass tube. Each technician took the visual measurement of every sample in triplicate.

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Image analysis. For the image analysis, a TRUAIT (Narjing, China) Pentium P166 computer was used for image acquisition, processing and analysis. Images were acquired using a Microtek ScanMaker E6 scanner and a Vcam CCD camera with the program ImageStar II (Taiwan). The hue, saturation, and intensity (HSI) domain is chosen to quantify oil color by image analysis method since this representation is closest to that of human perception, and use of the hue domain allows easy determination of oil color. However, color image information is often sensed using a combination of Red, Green, and Blue (R,G,B) values, although humans do not perceive color in this manner. Transforming the RGB color information to a single hue buffer helps to compress information for easier color discrimination. Hue is calculated from the RGB values by the following formulas (12):

$$G < B, \quad H = \frac{1}{360°}\left[90° - tg^{-1}\frac{F}{\sqrt{3}} + 0°\right] \qquad [1]$$

$$G > B, \quad H = \frac{1}{360°}\left[90° - tg^{-1}\frac{F}{\sqrt{3}} + 180°\right] \qquad [2]$$

where $F = (2 \times R - G - B)/(G - B)$. Then hue value is generated from image analysis. First, combined Lovibond glasses were used to build models between colorimeter and image analysis. Least squares regression was applied to red readings of each glass set vs. the hue values of the corresponding captured image. It was found that hue value was highly negatively correlated with Lovibond red reading. Conversely, the Lovibond red value of the image analysis method can be obtained from the hue value according to the following model:

$$\log \text{(automatic Lovibond red reading)} = a - b \times \text{Hue} \qquad [3]$$

All algorithms were developed using the C programming language.

The corrected model can be used to determine oil color, and an optical glass cell is designed to provide a 30-mm optical path. Color readings of samples were evaluated by image analysis immediately before or after their visual color values were taken. Temperature effects were ignored, and measurements were carried out at room temperature during the experiment. Statistical analyses are used for the data analysis.

RESULTS AND DISCUSSION

When oil color is seen by the human eye, it is equal to the three components hue, saturation, and intensity. Hue values represent the wavelength of various colors; therefore, the discrimination of different oil color means comparison to different hue values. As defined in GB5525-85, yellow color glass is fixed at a different scale for different types of oil, e.g., soybean and fragrant sesame oils are fixed at a 70 yellow reading, rapeseed oil and cottonseed oil are fixed at 35, peanut oil for cooking is fixed at a 25 yellow reading, and so on. Thus, it is not useful to correlate the yellow readings from these two different methods. Therefore, only the red color of visual measurements, according to Chinese national standard GB5525-85 (2), and the automatic red value from the image analysis method are presented.

Six sets of standard glasses are used to build models between image analysis and tintometer, in which different red glasses are combined with fixed yellow standard glass valued at 15, 20, 25, 30, 35, and 70, respectively, according to GB5525-85. Replicates obtained from image analysis method are completely identical when the combination of glasses is constant, in other words, the repeatability of the image analysis method is perfect (Table 1). Table 1 also listed coefficients a and b of the models and the correlation coefficients when various yellow standard glasses were used. The image analysis method uses different formulas to determine different types of oil. Owing to various factors such as different kinds of lamp housing and different cell length, the formulas of image analysis need to be corrected to measure oil color.

The color of each oil sample was determined by visual method and image analysis. The results are listed in Table 2. For the data of three operators from two laboratories, correlation slopes and intercepts are also close to their corresponding theoretical values of 1 and 0, with correlation coefficients ranging from 0.998 to 0.999. If all oil samples are considered, a very good linearity between the mean visual readings and the image analysis data is observed from Figure 1.

This study demonstrates that the image analysis method can be used effectively to determine the color of cottonseed oil, rapeseed oil, fragrant sesame oil, peanut oil and soybean oil. Its repeatability and reproducibility are adequate for the

TABLE 1
Hue Values of Standard Lovibond Glass Sets and Their Relationship

	Combined standard Lovibond red glass scale											Coeffients and related coeffient		
Yellow scale	1	2	3	4	5	6	7	8	9	10	S_r^a	a^c	b^c	r^c
15	50	41	33	28	25	23	20	19	19	17	0	1.460	0.029	–0.995
20	50	41	34	29	26	23	21	20	19	18	0	1.491	0.030	–0.997
25	51	43	36	32	29	26	24	23	22	20	0	1.616	0.031	–0.998
30	51	43	37	31	29	26	24	23	23	19	0	1.605	0.031	–0.995
35	52	45	39	34	32	28	26	25	24	22	0	1.728^b	0.033^b	-0.998^b
70	54	48	41	37	35	31	28	27	26	22	0	1.736^b	0.031^b	-0.995^b

[a]S_r, repeatability standard deviation in units of hue of combined Lovibond standard glasses by image analysis method.
[b]Combined standard Lovibond red glass scale ranging from 0 to 20.
[c]Coefficients (*a,b*) and correlation coefficient of the models of image analysis method.

TABLE 2
Lovibond-Red Color of Oil Samples by Image Analysis and Visual Colorimeter Methods

Source of data	Image analysis Red reading		Visual reading Technician 1		Visual reading Technician 2		Visual reading Technician 3		Three visual reading	
Peanut oil	Mean	S_r[a]	Mean	S_r	Mean	S_r	Mean	S_r	Mean	S_R[b]
P01	0.9	0	0.6	0.1	1.0	0.1	0.8	0.1	0.8	0.2
P02	0.9	0	0.9	0.1	1.0	0	0.8	0	0.9	0.1
P03	1.0	0	1.0	0	1.0	0.1	1.0	0.1	1.0	0
P04	1.0	0	1.0	0	1.1	0.1	1.2	0.1	1.1	0.1
P05	1.1	0	1.0	0.2	1.2	0.2	1.1	0.1	1.1	0.1
P06	1.0	0	0.9	0.2	1.0	0.1	1.0	0.1	1.0	0.06
P07	1.1	0	1.1	0	1.1	0.1	1.1	0.1	1.1	0
P08	1.2	0	0.9	0.1	1.0	0.2	1.0	0	1.0	0.06
P09	0.9	0	0.9	0.1	1.2	0	1.0	0.1	1.0	0.2
P10	1.1	0	1.2	0.1	1.2	0.1	1.2	0.1	1.2	0
P11	1.1	0	1.0	0	1.1	0	1.1	0	1.1	0.06
P12	1.0	0	0.9	0.1	1.1	0.1	1.0	0	1.0	0.1
P13	1.1	0	1.0	0.1	1.4	0.2	1.0	0.1	1.1	0.2
P14	1.1	0	1.1	0.1	1.2	0	1.2	0.1	1.2	0.06
P15	0.9	0	0.9	0.1	1.0	0.1	0.9	0	0.9	0.06
P16	0.9	0	0.8	0.1	0.9	0.1	0.9	0.1	0.9	0.06
P17	0.9	0	1.0	0	1.0	0.1	1.0	0.2	1.0	0
Cottonseed oil										
C01	5.0	0	4.5	0.3	5.0	0.2	4.7	0	4.7	0.3
C02	5.3	0	5.1	0.2	5.2	0.1	5.0	0.1	5.1	0.1
C03	6.2	0	5.9	0.1	6.8	0.1	6.2	0.1	6.3	0.5
C04	10.4	0	10.3	0.1	10.8	0.2	10.5	0.2	10.5	0.3
C05	6.2	0	6.5	0.2	7.0	0	6.9	0	6.8	0.3
C06	7.7	0	8.0	0	8.0	0.1	8.0	0.1	8.0	0
Rapeseed oil										
R01	5.9	0	5.5	0.1	6.0	0.1	5.8	0.1	5.7	0.3
R02	5.3	0	5.0	0	5.0	0.2	5.0	0.1	5.0	0
R03	6.8	0	7.0	0.2	7.0	0.1	7.0	0	7.0	0
R04	5.9	0	6.0	0.1	6.0	0.2	6.0	0.2	6.0	0
R05	10.4	0	10.0	0.2	10.5	0	10.4	0.1	10.3	0.3
Soybean oil										
S01	5.6	0	5.5	0.1	6.2	0.1	5.8	0.1	5.8	0.4
S02	4.8	0	4.3	0	5.0	0.2	5.0	0	4.8	0.4
S03	5.5	0	5.3	0.2	6.0	0	6.0	0.2	5.8	0.4
S04	4.6	0	4.2	0.2	4.6	0	4.5	0.1	4.4	0.2
S05	4.9	0	4.5	0.1	5.5	0.2	5.3	0.2	5.1	0.5
S06	4.1	0	4.0	0	4.2	0.2	3.9	0.1	4.0	0.2
S07	5.1	0	5.0	0.1	5.5	0.1	5.3	0.1	5.3	0.3
S08	5.3	0	5.0	0.2	5.1	0.1	5.0	0.1	5.0	0.06
S09	4.3	0	3.8	0.1	4.3	0.1	4.0	0.2	4.0	0.3
S10	4.8	0	4.5	0.2	5.0	0	4.9	0	4.8	0.3
Fragrant sesame oil										
F01	7.1	0	6.8	0.1	7.5	0.1	7.0	0	7.1	0.4
F02	15.3	0	14.8	0.2	15.5	0	15.3	0.1	15.2	0.4
F03	13.5	0	12.6	0.1	14.0	0.2	13.0	0.2	13.2	0.7
F04	14.8	0	14.5	0.2	15.5	0.1	15.0	0.1	15.0	0.5
F05	10.6	0	10.5	0	12.0	0.2	11.5	0	11.0	0.8
F06	9.2	0	9.0	0	10.0	0.1	9.5	0.2	9.5	0.5
F07	9.8	0	10.0	0.1	10.0	0.1	10.0	0.2	10.0	0
F08	8.7	0	8.2	0.1	9.0	0.3	8.5	0.1	8.6	0.4
F09	15.2	0	14.0	0	16.0	0	15.0	0.1	15.0	1
F10	18.7	0	18.0	0.2	20.0	0.2	19.0	0.2	19.0	1
F11	6.5	0	6.0	0.1	7.0	0.2	6.5	0	6.5	0.5

[a]S_r, repeatability standard deviation in Lovibond red color unit.
[b]S_R, reproducibility standard deviation in Lovibond red color unit of technicians.

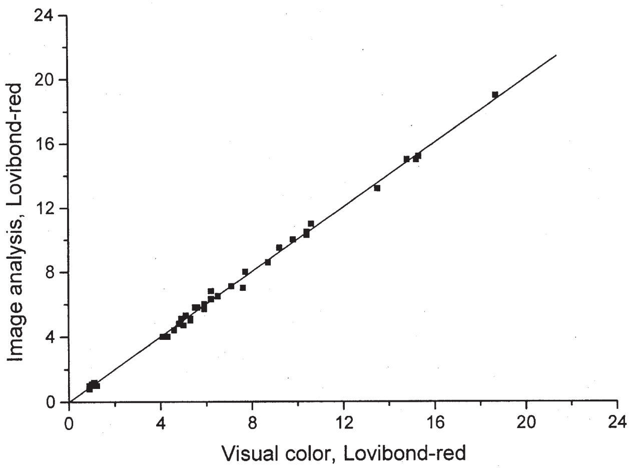

FIG. 1. Image analysis red in Lovibond unit vs. visual Lovibond-red for all oil samples.

study of oil quality in terms of its color appearance. The image analysis method made it possible to avoid operator variability associated with visual comparison.

Using digital image analysis to measure edible oil color not only gives objective results but also simplifies the preparation of test samples. ISO 15305 specifies that the fat or oil shall be completely liquid, clear, and bright when the determination is made. In the image analysis method any form of samples can be tested. It is easy to operate without the problem of operator variability. When proper correlation with a variety of oil types is established, image analysis may be the preferred method for measuring oil color. With broad application of the CCD full color camera, image analysis could be widely used for determination of oil color. In the image analysis method the effect of light strength on red readings was not presented in this paper, so it still needs to be investigated.

ACKNOWLEDGMENTS

The authors express sincere appreciation to the members of the Inspection Office of Henan Grain Bureau who supplied the valuable oil samples, and the laboratory of the Inspection Office who provided the visual color measurements.

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[Received May 16, 2000; accepted March 21, 2001]