Comparison of Visual and Automated Colorimeters—An International Collaborative Study

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ABSTRACT: Color as a fundamental quality of edible oils has been determined primarily by visual comparison methods for many decades. The automatic colorimeters introduced recently made it possible to replace the manually operated visual color instrument, which requires experience to master and is often subject to operator variabilities. A previous study with an automatic colorimeter, Colourscan, to measure the colors of refined and refined bleached cottonseed oils showed good agreement (r^2 = 0.99) with visual color measurements by means of the Lovibond-AOCS Color Scale. The current work is to establish a broad-scale correlation between the automated colorimeter and visual color measurements. In this international effort, factory-processed refined and refined, bleached, deodorized (RBD) canola, corn, cottonseed, peanut, sunflower and soybean oils, as well as refined palm olein, RBD palm oil, and washed, dried, filtered and deodorized tallow were used. A total of 14 laboratories from the United States and Canada, and 16 laboratories from 12 countries outside of North America, participated in this collaborative study. The results of this study, with statistical analyses, are reported.
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KEY WORDS: Automated colorimeter, canola, corn, cottonseed, Lovibond, palm, peanut, soy, sunflower oil, tallow, visual color, Wesson method.

Color is an important quality parameter of edible oil, both in the processing environment and the marketplace. For instance, color is often used as the principal benchmark for refining. Color is also frequently monitored as an indicator for the condition of oil before and after frying. Sometimes, oil color is used as the basis for acceptance or rejection of oil in the trade. Owing primarily to naturally occurring polyphenolic pigments, gossypol, chlorophyll, carotenoids, etc., each oil has its own characteristic color before, during, and after the normal refining process (1). Thus, oil color is often specified in the trading rules established by various trade associations. For example, prime crude cottonseed oil should not exceed 7.6 AOCS red after caustic refining, and prime bleachable summer yellow (PBSY) cottonseed oil should be bleachable to less than 2.5 AOCS red (2).

Lovibond color of oil is an arbitrary scale and the most widely used in the edible oils industry (3). It is a visual comparison method in which a colorimeter is used that is equipped with a set of colored glasses designed according to either the British Lovibond Color Scale (Lovibond Scale) or the AOCS Tintometer Wesson Color Scale (AOCS Scale). Lovibond Color Standards and the AOCS Tintometer Color Scale or the Wesson Method are described in the AOCS Official Methods, Cc 13e-92 and Cc 13b-45, respectively (4). The Lovibond method, Cc 13e-92, requires a Model E Lovibond Tintometer and red, yellow, blue, and neutral glasses to match the oil color and is practiced primarily outside of the United States and Canada. The Wesson method, published as AOCS Official Method Cc 13b-45 in 1945 (4,5), requires the AF710 AOCS Tintometer to match the oil color with red and yellow glasses.

These methods are accurate but require an experienced observer to achieve the desired reliability and repeatability. With approximately 8% of males and 0.4% of females suffering from varying degrees of color blindness, the potential to have an operator with defective color vision is rather high (3). To eliminate operator variability, attempts to use an instrument to replace the visual color measurement have been made. A collaborative effort in the late 1940s (6) led to the development of an official spectrophotometric color method, Cc 13c-50 (4), in which matched glass cylindric cuvettes of approximately 21.8 mm i.d. are used to read absorbance at 460, 550, 620, and 670 nm. This method showed good correlation with the visual Lovibond method (r^2 = 0.993) and is a potential alternative to the manual Lovibond method (7). However, the spectrophotometric method is seldom used (8).

In recent years, automated colorimeters have become available, primarily from Tintometer Ltd. (Salisbury, England) (3). Initial collaborative efforts to correlate the automatic Tintometer Model AF960 with the manual Tintometer Model AF710 did not produce an acceptable conclusion or recommendation (9). Recent work by Wan and Pakarinen (10) has demonstrated that the Colourscan, which is a personal computer-based colorimeter introduced by the Tintometer Ltd., can give red color readings of refined and refined, bleached cottonseed oils with good agreement vs. the values obtained by the visual Tintometer (r^2 = 0.99). The present work was initiated to establish a broad correlation between the visual method or manual Tintometer AF710 or AF900

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with an automated colorimeter, PFX990, which is an improved version of the Colourscan, for refined and refined, bleached-deodorized (RBD) canola, corn, cottonseed, peanut, sunflower and soybean oils, as well as refined palm olein, RBD palm oil, and for washed, dried, filtered and deodorized tallow with a cell of 133.4-mm (5-1/4″) light path.

EXPERIMENTAL PROCEDURES

Participating laboratories. Many laboratories responded to the open invitation for this international collaborative study on oil color. A total of 30 laboratories from 14 countries volunteered to participate in this study. From North America (NA), there are 11 laboratories from the United States and 3 from Canada. Outside of North America (EU), there were one laboratory each from Czech Republic, France, Indonesia, Italy, Jamaica, the Netherlands, Saudi Arabia, Spain, and Turkey; two each from Belgium and Germany; and three from the United Kingdom. After a period of reviewing and commenting on the test protocol, a set of 18 oil samples was sent to each participating laboratory by express delivery. Each laboratory was asked to conduct the test within a week from the time the samples were received and reminded that six specific samples should be melted thoroughly at 55°C prior to measuring color.

Samples, standards and apparatus. All 18 oil samples, individually stored in 4-oz brown-colored plastic bottles and coded with random numbers, were sent to each of the 30 participating laboratories by express delivery. These oils were factory-produced refined and RBD canola, corn, cottonseed, peanut, sunflower and soybean, as well as refined palm olein, RBD palm, and washed, dried, filtered and deodorized tallow, along with duplicate samples of refined and RBD soy as built-in check samples. Three to four laboratories also shared a set of three color standard glasses, which were specially prepared to fit both the automated colorimeter and the visual Tintometer. All participating laboratories had access to an automated colorimeter (model PFX 990) and an official visual colorimeter (model AF710) for the facilities in North America and a model AF900 or equivalent for those outside of North America. Both automated and visual colorimeters and standard glasses were manufactured by The Tintometer Ltd.

Method. For visual color measurements, NA laboratories followed AOCS Method Cc 13b-45 (Wesson method) with a Tintometer Model AF710 (The Tintometer Ltd.) and a 133.4-mm (5-1/4″) sample glass tube, and laboratories EU followed AOCS Cc 13e-92 (Lovibond method) with a visual Tintometer Model AF900 (4). When yellow color of oil was read, especially for dark oils, each participant was reminded to start with 10 times of red but report the best match of yellow value with the visual Tintometer. Automated color measurements generally followed recommendations of the manufacturer (10). All color readings were done with the oil sample temperature maintained at 30°C, except for tallow, palm and cottonseed, which were thoroughly melted at 55°C before color readings were taken. All oils were examined in a cell of 133.4-mm (5-1/4″) light path, and duplicate readings were requested for both visual and automated color measurements.

Statistical analysis. Data were collected by the staff at AOCS headquarters and analyzed according to AOCS Procedure M1-92 (4) and by the statistician at the Southern Regional Research Center (New Orleans, LA) by means of SAS. Least-squares linear regression was applied to each set of visual color readings vs. corresponding automated color values. The errors of their slopes and intercepts were also assessed at the 95% confidence level.

RESULTS AND DISCUSSION

A total of 27 out of 30 laboratories from 14 countries (15 EU and 12 NA) sent back their results. Their color readings and dates when the oil colors were measured can be found in the Final Report submitted to the AOCS Technical Department (11). A total of 12 out of the 15 EU collaborators measured the colors of oil samples within the last week of January 1996. A total of 10 of the 12 participants from NA completed their color readings from January 11 to January 28, 1996. At the beginning of this study, a set of 18 oil samples was kept in ambient conditions, and colors were read periodically with an automated Colourscan colorimeter (10). Some changes in colors of these samples were noted. However, changes in color for the refined oil group were less than 5% of the AOCS red scale with the exception of refined canola, which decreased by about 12% from its initial red reading during the 2 wk of storage at room temperature. During the same period, RBD oil samples showed little change in red color. Only 0.1 and 0.2 unit increases in AOCS red scale were observed for some of the RBD oils. Color data of all oil samples were taken as reported for statistical analysis without time-related corrections for minor color changes during the collaborative study. However, owing to the large variations in visual color readings of refined canola oil samples from the participating laboratories, refined canola oil color data were excluded from further correlation analysis.

Red and yellow color readings from all 27 facilities were statistically analyzed separately for each individual oil. Samples of these analyses are shown in Tables 1–4 for red and yellow color measurements of canola and soybean oil, respectively. Tables of statistical analysis for the color readings of other oils, including the duplicate set of soybean oil samples and three standard glasses, are displayed in the same Final Report submitted to the AOCS Technical Department (11). Because AOCS and Lovibond color scales are slightly different, the statistical analysis for each oil is done by dividing the collaborators into two separate groups for each oil sample. NA collaborators, who normally use the AOCS color scale, include 9 from the United States and 3 from Canada. The second group of 15 collaborators, routinely using the Lovibond color scale, is from EU countries. The symbols used in Tables 1–4 are defined as follows: S_r = repeatability standard deviation in red or yellow color units, RSD_r = repeatability relative standard deviation in percentage, $r = 2.8 \times S_r$ = repeatability

TABLE 1
Canola Oil—Red Color

	Method											
	AOCS/990		Lovibond/990		Visual[a]		AOCS/990		Lovibond/990		Visual	
	Sample[b]											
	C		C		C		J		J		J	
	Country[c]											
	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America
Labs after outliers	11	10	13	8	10	4	12	12	15	10	12	12
Labs removed	0	2	0	1	1	0	0	0	0	0	2	0
Accepted values, *n*	22	20	26	16	19	8	24	24	30	20	24	23
Mean, × red	8.4	10.2	7.8	9.5	12.8	14.7	1.3	1.3	1.2	1.2	0.9	0.8
S_r	0.16	0.16	0.12	0.17	0.07	2.9	0.02	0.06	0.03	0.03	0.04	0.06
RSD_r	1.85	1.61	1.51	1.83	0.55	19.68	1.56	4.55	2.69	2.64	3.77	6.60
r	0.43		0.33	0.48	0.20	8.13	0.06	0.17	0.09	0.09	0.10	0.16
S_R	3.33	0.95	2.78	0.69	7.43	12.07	0.16	0.20	0.12	0.16	0.21	0.30
RSD_R	39.61	9.32	35.83	7.27	58.31	81.78	12.43	14.66	10.06	13.59	22.68	34.75
R	9.32	2.66	7.79	1.93	20.81	33.81	0.46	0.55	0.33	0.46	0.60	0.83
R/r	21.7	5.8	23.6	4.0	104.1	4.2	7.7	3.2	3.7	5.1	6.0	5.2

[a]Results unacceptable.
[b]C, refined canola oil; J, RBD canola oil.
[c]EU, outside North America; S_r, repeatability standard deviation; RSD_r, repeatability relative standard deviation; RSD_R, reproducibility relative standard deviation, R, reproducibility; r, repeatability; SR, reproducibility standard deviation.

value in red or yellow color units, S_R = reproducibility standard deviation in red or yellow color units, RSD_R = reproducibility relative standard deviation in percentage, $R = 2.8 \times S_R$ = reproducibility value in red or yellow color units. As expected, the repeatabilities, r, of visual and automated color readings within each laboratory were very good for either NA or EU labs, and its RSD_r were generally much less than 5%, while the R of visual and automated color readings between collaborators were 2–7 times greater than those of r, as reflected by consistently greater RSD_R than RSD_r. Some of the RSD_R values for visual red color readings, as high as 23–35% between laboratories, or values of R/r much larger than 1–4,

TABLE 2
Canola Oil—Yellow Color[a]

	Method											
	AOCS/990		Lovibond/990		Visual		AOCS/990		Lovibond/990		Visual	
	Sample											
	C		C		C		J		J		J	
	Country											
	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America
Labs after outliers	12	12	13	8	10	4	11	12	12	9	10	11
Labs removed	0	1	0	1	2	0	1	0	3	1	4	1
Accepted values, *n*	22	22	26	16	19	7	22	24	24	18	20	20
Mean, × yellow	70.0	70.0	70.0	70.0	55	63.7	8.9	9.4	10.4	11.4	9.5	8.6
S_r	0.00	0.00	0.08	0.00	1.75	4.08	0.02	0.13	0.03	0.00	0.19	0.62
RSD_r	0.00	0.00	0.11	0.00	3.18	6.40	0.24	1.34	0.28	0.00	1.98	7.26
r	0.00	0.00	0.22	0.00	4.90	11.43	0.06	0.35	0.08	0.00	0.53	1.75
S_R	0.00	0.00	0.08	0.00	21.28	13.44	0.50	0.84	0.86	0.66	0.51	1.21
RSD_R	0.00	0.00	0.11	0.00	38.69	21.08	5.66	8.98	8.23	5.83	5.37	14.07
R	0.00	0.00	0.22	0.00	59.58	37.62	1.41	2.36	2.40	1.85	1.43	3.38
R/r			1.0		12.2	3.3	23.5	6.7	30.0		2.7	1.9

[a]See Table 1 footnotes.

TABLE 3
Soybean Oil—Red Color[a]

	Method											
	AOCS/990		Lovibond/990		Visual		AOCS/990		Lovibond/990		Visual	
	Sample[a]											
	F		F		F		O		O		O	
	Country[b]											
	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America
Labs after outliers	10	11	11	9	11	10	11	12	15	10	12	12
Labs removed	2	0	3	1	3	2	1	0	0	0	2	0
Accepted values, *n*	20	22	22	18	22	19	22	24	30	20	24	23
Mean, × red	10.4	10.3	9.8	9.5	10.0	9.0	0.9	0.9	0.9	0.9	0.8	0.5
S_r	0.07	0.06	0.03	0.06	0.29	0.09	0.00	0.04	0.03	0.06	0.04	0.04
RSD_r	0.65	0.55	0.31	0.61	2.88	0.98	2.46	4.62	2.96	6.95	4.49	7.75
r	0.19	0.16	0.08	0.16	0.81	0.25	0.06	0.11	0.07	0.18	0.10	0.12
S_R	0.38	0.47	0.35	0.63	0.35	0.74	0.09	0.13	0.11	0.10	0.21	0.13
RSD_R	3.66	4.60	3.62	6.59	3.54	8.22	9.88	14.31	12.95	11.41	26.87	23.61
R	1.06	1.32	0.99	1.76	0.99	2.08	0.24	0.35	0.32	0.29	0.59	0.36
R/r	5.60	8.2	12.4	11.0	1.2	8.3	4.0	3.2	4.6	1.6	5.9	3.0

[a]F, refined soybean oil; O, refined, bleached, deodorized soybean oil.

[b]See Table 1, footnote *c*.

indicated the large variations among collaborators that are usually involved with visual color measurements (Tables 1–4). From the statistical analysis for red and yellow colors of all eight oil types after refining and deodorizing, some general observations can be made. The precision of both visual and automated methods for each oil type and standard glass, as shown by their r within each laboratory, RSD_r, reproducibility among laboratories, R, and RSD_R, is largely acceptable and quite encouraging.

The statistical analyses for each of the 18 oil samples and three standard glasses were evaluated similar to the sample results shown in Tables 1–4. To simplify the discussion, only the mean red and yellow values of the 18 oil samples, measured by automated and visual instruments, are displayed in Tables 5 and 6, respectively. Least-squares linear regression analysis for these mean values of red and yellow color measurements is exhibited in Tables 7 and 8. Correlations between the automated colorimeter and visual measurements

TABLE 4
Soybean Oil—Yellow Color[a]

	Method											
	AOCS/990		Lovibond/990		Visual		AOCS/990		Lovibond/990		Visual	
	Sample											
	F		F		F		O		O		O	
	Country											
	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America	EU	North America
Labs after outliers	12	12	14	10	10	10	11	10	13	9	11	11
Labs removed	0	0	0	0	4	2	1	2	2	1	3	1
Accepted values, *n*	24	24	28	20	20	19	22	20	26	18	22	21
Mean, × yellow	70.0	70.0	70.0	70.0	70.2	71.8	5.3	5.5	6.1	6.3	6.0	5.4
S_r	0.00	0.00	0.00	0.00	0.96	0.00	0.03	0.10	0.03	0.11	0.13	0.32
RSD_r	0.00	0.00	0.00	0.00	1.36	0.00	0.56	1.78	0.55	1.81	2.11	5.90
r	0.00	0.00	0.00	0.00	2.67	0.00	0.08	0.27	0.10	0.32	0.35	0.89
S_R	0.00	0.00	0.00	0.00	3.95	3.87	0.22	0.59	0.37	0.36	0.49	1.13
RSD_R	0.00	0.00	0.00	0.00	5.63	5.39	4.08	10.85	6.04	5.77	8.14	21.01
R	0.00	0.00	0.00	0.00	11.06	10.84	0.61	1.66	1.04	1.01	1.36	3.16
R/r					4.10		7.6	6.1	10.4	3.2	3.9	3.6

[a]See Table 3 footnotes.

TABLE 5
Means of Red Values—1996 International Oil Color Study[a]

Oil type	Refined or RBD oil[a]	Automated AOCS–EU[b]	Automated AOCS–NA[c]	Automated Lovibond–EU	Automated Lovibond–NA	Visual–EU	Visual–NA	Known red values EU	Known red values NA
Canola	Refined	8.4	10.2	7.8	9.5	12.8	14.7		
Corn	Refined	11.0	10.8	10.4	10.2	9.6	8.9		
Cottonseed	Refined	15.2	17.3	13.0	15.9	11.7	12.7		
Palm olein	Refined	3.2	3.1	3.1	3.1	3.1	2.8		
Peanut	Refined	2.9	2.9	3.1	3.1	2.9	2.7		
Soybean	Refined	10.4	10.3	9.8	9.5	10.0	9.0		
Soybean—duplicate	Refined	10.4	10.3	9.9	9.7	10.0	9.0		
Sunflower	Refined	3.7	3.4	3.5	3.5	2.7	2.9		
Tallow	Wash, dry, filtered	1.9	1.9	1.8	1.8	1.4	1.5		
Canola	RBD	1.3	1.3	1.2	1.2	0.9	0.8		
Corn	RBD	1.8	1.7	1.9	1.9	1.5	1.2		
Cottonseed	RBD	3.3	3.2	3.5	3.2	2.9	2.9		
Palm	RBD	2.9	3.0	3.1	3.0	2.8	2.9		
Peanut	RBD	1.0	1.0	0.9	0.9	0.9	0.6		
Soybean	RBD	0.9	0.9	0.9	0.9	0.8	0.5		
Soybean—duplicate	RBD	0.9	0.9	0.9	0.9	0.7	0.5		
Sunflower	RBD	0.9	1.0	0.9	1.0	0.8	0.6		
Tallow	Deodorized	2.3	2.3	2.1	2.1	1.8	1.3		
Glass standard-1		0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Glass standard-2		3.8	3.7	3.5	3.5	3.3	3.4	3.3	3.5
Glass standard-3		6.7	6.6	6.6	6.4	6.1	6.5	6.2	6.4

[a]RBD, refined, bleached, deodorized.
[b]EU, laboratories outside of North America.
[c]NA, laboratories from North America.

for red colors of refined and RBD oils were generally acceptable as shown by the values of r^2, slopes close to 1, and intercepts near zero. The least-squares linear correlation of red colors for combined refined and RBD oils were also acceptable. The regression results for the three standard glasses by either automated or visual measurements were near perfect, which implies that all instruments and visual operators functioned as well as expected.

Correlations of the mean values of yellow colors for refined oils between automated and visual measurements were

TABLE 6
Means of Yellow Values—1996 International Oil Color Study[a]

Oil type	Refined or RBD oil	Automated AOCS–EU	Automated AOCS–NA	Automated Lovibond–EU	Automated Lovibond–NA	Visual–EU	Visual–NA	Known yellow values EU	Known yellow values NA
Canola	Refined	70.0	70.0	70.0	70.0	55.0	63.7		
Corn	Refined	70.0	70.0	70.0	70.0	52.4	57.6		
Cottonseed	Refined	70.0	70.0	70.7	70.0	72.0	71.4		
Palm olein	Refined	50.0	49.8	54.2	53.9	47.2	29.8		
Peanut	Refined	70.0	70.0	70.0	69.9	67.4	43.3		
Soybean	Refined	70.0	70.0	70.0	70.0	70.2	71.8		
Soybean—duplicate	Refined	70.0	70.0	70.0	70.0	68.9	72.1		
Sunflower	Refined	70.0	70.0	66.8	70.4	64.4	30.4		
Tallow	Wash, dry, filtered	33.7	34.9	37.4	40.4	34.5	21.9		
Canola	RBD	8.9	9.4	10.4	11.4	9.5	8.6		
Corn	RBD	11.5	11.4	13.3	13.2	13.2	10.1		
Cottonseed	RBD	34.2	35.0	35.8	40.1	31.9	29.6		
Palm	RBD	46.7	45.5	50.7	51.0	43.3	30.2		
Peanut	RBD	4.1	4.3	4.7	4.9	4.8	4.0		
Soybean	RBD	5.3	5.5	6.1	6.3	6.0	5.4		
Soybean—duplicate	RBD	5.3	5.2	6.0	6.0	6.1	5.0		
Sunflower	RBD	4.2	4.6	4.8	5.4	5.1	4.7		
Tallow	Deodorized	5.4	5.7	6.3	6.7	6.6	4.5		
Glass standard-1		1.0	1.0	1.1	1.1	1.2	0.9	1.3	1.0
Glass standard-2		13.0	13.0	15.1	15.1	16.1	16.5	17.0	13.0
Glass standard-3		38.0	38.0	51.0	51.0	49.4	38.7	50.0	37.0

[a]See Table 5 for footnotes.

TABLE 7
Least Square Linear Regression for Red Color: *Y* = Intercept + Slope (*X*)

Dependent variable *Y*	Independent variable *X*	R-Square	Intercept	Standard error	Slope	Standard error
For refined oils[a]						
AOCS–NA	Visual–NA	0.983	–0.574	0.511	1.305	0.070
Lovibond–EU	Visual–EU	0.986	0.266	0.377	1.021	0.050
Visual–EU	Visual–NA	0.975	0.216	0.485	1.003	0.066
AOCS–EU	AOCS–NA	0.987	0.484	0.384	0.900	0.042
Lovibond–EU	Lovibond–NA	0.965	0.698	0.573	0.863	0.068
Lovibond–EU	AOCS–NA	0.962	0.984	0.578	0.779	0.064
Visual–NA	AOCS–(NA + EU)	0.987	0.320	0.216	0.791	0.024
Visual–EU	Lovibond–(NA + EU)	0.946	0.279	0.463	0.883	0.056
For refined, bleached, deodorized oils (RBD)[b]						
AOCS–NA	Visual–NA	0.94	0.557	0.135	0.910	0.087
Lovibond–EU	Visual–EU	0.986	0.029	0.087	1.155	0.052
Visual–EU	Visual–NA	0.975	0.350	0.083	0.881	0.053
AOCS–EU	AOCS–NA	0.994	–0.023	0.055	1.013	0.029
Lovibond–EU	Lovibond–NA	0.996	–0.129	0.052	1.097	0.028
Lovibond–EU	AOCS–NA	0.982	–0.151	0.107	1.095	0.056
Visual–NA	AOCS–(NA + EU)	0.933	–0.479	0.130	1.020	0.068
Visual–EU	Lovibond–(NA + EU)	0.983	–0.054	0.056	0.891	0.029
For refined oils and refined, bleached, deodorized oils combined[a,b]						
AOCS–NA	Visual–NA	0.984	0.013	0.208	1.235	0.041
Lovibond–EU	Visual–EU	0.992	0.218	0.130	1.028	0.024
Visual–EU	Visual–NA	0.985	0.213	0.163	1.001	0.032
AOCS–EU	AOCS–NA	0.991	0.230	0.145	0.931	0.023
Lovibond–EU	Lovibond–NA	0.978	0.307	0.208	0.901	0.035
Lovibond–EU	AOCS–NA	0.974	0.462	0.225	0.825	0.035
Visual–NA	AOCS–(NA + EU)	0.988	–0.046	0.100	0.825	0.016
Visual–EU	Lovibond–(NA + EU)	0.970	0.002	0.165	0.909	0.028
For standard color glasses						
AOCS–NA	Visual–NA	0.999	0.255	0.118	0.984	0.028
Visual–NA	Known–NA	1.000	–0.243	0.043	1.051	0.010
AOCS–NA	Known–NA	1.000	0.015	0.081	1.034	0.019
Lovibond–EU	Visual–EU	1.000	–0.028	0.041	1.089	0.010
Visual–EU	Known–EU	1.000	0.025	0.040	0.982	0.010
Lovibond–EU	Known–EU	1.000	0.000	0.085	1.070	0.021
Visual–EU	Visual–NA	1.000	0.229	0.000	0.903	0.000
AOCS–EU	AOCS–NA	1.000	0.007	0.039	1.017	0.009
Lovibond–EU	Lovibond–NA	1.000	–0.018	0.001	1.034	0.000
Lovibond–EU	AOCS–NA	1.000	–0.031	0.083	0.999	0.019

[a]Red color data of Refined Canola Oil were excluded from these regression analysis.
[b]Lovibond–EU–Red and Visual–EU–Red for RBD sunflower oil tested by labs outside of North America were excluded from the regression analysis for the variables with suffix of EU due to unreasonably large deviation.

quite poor, with r^2 values lying between 0.46 and 0.72 and intercepts deviating significantly from zero when automated colorimeter readings were compared with visual measurements. This was primarily due to the yellow values of these refined oils, which well exceeded the saturation point of automated and/or visual colorimeter yellow scales. Most of the correlations between automated yellow readings and visual yellow values for the RBD oils were acceptable. Correlation parameters between automated yellow readings and visual yellow values for three standard glasses were again near perfect.

While the correlations between automated and visual measurements of red and yellow colors of oils were generally acceptable, the following trends were observed. Visual color readings of oils were slightly lower than the automated color results for both the AOCS or Lovibond color scales. The differences ranged from 0.1–0.6 units of red for RBD oils, 0.1–1.3 units of red for refined oils, and 0.1–1.3 units of yellow for the RBD oils, excluding cottonseed and palm. Visual color in the AOCS scale was generally lower than the Lovibond visual reading by 0.1–0.5 units of red for RBD oils, 0.1–1.0 units of red for refined oils and 0.6–3.1 units of yellow for RBD oils, excluding cottonseed and palm (Tables 5 and 6). The majority of the correlations were reasonably good, with their slopes and r^2 values close to one, as indicated by the regression results in Tables 7 and 8. Except for yellow color readings of refined oils, the linearity of the mean values of automated color measurements vs. visual color readings

TABLE 8
Least Square Linear Regression for Yellow Color: *Y* = Intercept + Slope (*X*)[a]

Dependent variable *Y*	Independent variable *X*	R-Square	Intercept	Standard error	Slope	Standard error
For refined oils[a]						
AOCS–NA	Visual–NA	0.506	40.864	9.166	0.448	0.167
Lovibond–EU	Visual–EU	0.722	19.357	10.756	0.761	0.178
Visual–EU	Visual–NA	0.463	37.193	9.521	0.427	0.174
AOCS–EU	AOCS–NA	1.000	–1.679	0.521	1.025	0.008
Lovibond–EU	Lovibond–NA	0.985	–4.536	3.288	1.060	0.050
Lovibond–EU	AOCS–NA	0.984	7.835	2.0806	0.885	0.043
Visual–NA	AOCS–(NA + EU)	0.504	–19.679	17.937	1.113	0.276
Visual–EU	Lovibond–(NA + EU)	0.723	–4.231	9.940	0.980	0.152
For refined, bleached, deodorized oils (RBD)						
AOCS–NA	Visual–NA	0.973	–1.868	1.341	1.405	0.088
Lovibond–EU	Visual–EU	0.999	–1.328	0.291	1.186	0.015
Visual–EU	Visual–NA	0.961	–0.367	1.471	1.271	0.097
AOCS–EU	AOCS–NA	0.999	–0.354	0.250	1.017	0.012
Lovibond–EU	Lovibond–NA	0.995	–0.117	0.592	0.960	0.026
Lovibond–EU	AOCS–NA	0.997	0.164	0.482	1.079	0.024
Visual–NA	AOCS–(NA + EU)	0.968	1.750	0.640	0.685	0.031
Visual–EU	Lovibond–(NA + EU)	0.996	1.090	0.279	0.824	0.012
For refined oils and refined, bleached, deodorized oils combined						
AOCS–NA	Visual–NA	0.842	6.727	4.480	1.029	0.111
Lovibond–EU	Visual–EU	0.969	0.881	2.137	1.065	0.048
Visual–EU	Visual–NA	0.836	7.218	4.176	0.937	0.104
AOCS–EU	AOCS–NA	1.000	–0.285	0.192	1.004	0.004
Lovibond–EU	Lovibond–NA	0.998	–0.672	0.608	1.000	0.012
Lovibond–EU	AOCS–NA	0.996	1.370	0.738	0.988	0.015
Visual–NA	AOCS–(NA + EU)	0.841	–0.419	2.924	0.816	0.061
Visual–EU	Lovibond–(NA + EU)	0.968	0.035	1.394	0.909	0.028
For standard color glasses						
AOCS–NA	Visual–NA	0.990	–1.157	2.402	0.989	0.099
Visual–NA	Known–NA	0.992	1.154	2.102	1.032	0.093
AOCS–NA	Known–NA	1.000	–0.173	0.234	1.030	0.010
Lovibond–EU	Visual–EU	0.999	–0.777	0.977	1.042	0.033
Visual–EU	Known–EU	1.000	–0.367	0.443	0.993	0.015
Lovibond–EU	Known–EU	0.998	–1.149	1.448	1.034	0.047
Visual–EU	Visual–NA	0.987	–1.896	3.668	1.290	0.151
AOCS–EU	AOCS–NA	1.000	0.000	0.000	1.000	0.000
Lovibond–EU	Lovibond–NA	1.000	0.000	0.000	1.000	0.000
Lovibond–EU	AOCS–NA	0.998	–1.207	1.518	1.362	0.065

[a]See Table 5 for abbreviations.

for all 18 oil samples and three standard glasses in AOCS and Lovibond scales are clearly indicated by these data. Their graphical presentations can be found in the Final Report (11).

From this international effort, it appeared that the automated colorimeter, such as the PFX990, may be considered as an appropriate alternative to AOCS official visual color methods Cc 13b-45 and Cc 13e-92 for edible oils (4). With the expectation of further improvement in the automated colorimeter at affordable cost, researchers and professionals in the edible oils industry will have a more efficient tool for routine oil color measurements and oil color-related research.

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