A METHOD FOR INSTRUMENTAL MEASUREMENT OF BARLEY COLOR[1,2]

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ABSTRACT
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The colors of 121 barley samples were determined by the Agtron, Hunter Color Difference Meter, Gardner Digital Difference Meter, and by visual inspection. Correlations were highly significant among instrument readings and between readings and visual color scores. Variability was low within instruments. A method is proposed for use of the Gardner Digital Difference Meter for determining the color of malting barley and a chart is presented for converting instrument reading to visual color score.

Barley kernel color is considered in establishing grain soundness (1) and is an important quality factor for maltsters and brewers. A bright, light-yellow barley is highly desirable. Staining or discoloration indicates that barley was subjected to wet weather at harvest time or to bacterial and/or fungal invasion (2–4). Discolored grain has been associated with some unsatisfactory beer properties (5–7).

According to the Official Grain Standards (8) all types of damaged kernels (except sprouted and frosted seeds) have some degree of kernel discoloration. Barley color is usually evaluated by visual comparison of the unknown sample with standard samples.

Human judgments are influenced by many factors which affect accuracy, precision, and reproducibility. During the last decade, efforts have been made to eliminate subjective evaluation of visual and sensory properties (9–13). The use of electronic devices to measure color eliminates many problems associated with methods requiring matching fields by the human eye. Reflectance-measuring spectrophotometers have been widely used for color grading of products including flour (9,11), semolina (14), spaghetti (15), cereal grains (16,17), and beers (10,12,18,19).

Gillis (9), using a modified Agtron Model F2-61, found a high correlation between flour ash and green Agtron values, and suggested flour color as a method for the prediction of ash content. Tables were developed relating Agtron color readings and flour ash content to provide a fast method for ash prediction in flour mills. A similar relation between mineral content and Agtron values of flour was shown by Shuey and Skarsaune (20), who used a new model M-500-A Agtron. They confirmed the usefulness of the reflectance readings for an ash-prediction method. Patton and Dishaw (11) recommended the green Agtron reading as a valuable tool for quality control of commercial white bread flours.

Matz and Larsen (14) investigated the use of different reflectometers to measure semolina color. They reported that the Densichron, Hunter Color-

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[2]Use of a company or product name does not imply approval or recommendation of the product by the U.S. Department of Agriculture to the exclusion of others which may also be suitable.

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Difference Meter, and Photovolt reflection meter were promising control instruments. Walsh (15) developed a method for measuring spaghetti color using photoelectric instruments. A color map was designed to be used with the reflectance values to determine spaghetti color scores.

Reflectance spectrophotometric methods for measuring barley color have been used for many years (16,17,21). Recently, Skarsaune *et al.* (22), using three instruments, reported a close relation between instrument readings and visual color scores of barley. However, they did not suggest a procedure for determining barley kernel color.

The objective of our research was to compare methods of assessing barley color and to develop a rapid, reliable, and reproducible instrumental method of color evaluation.

MATERIALS AND METHODS

Stained barley samples (121) were collected from the federally licensed North Dakota Grain Inspection Service and were malting types of unidentified varieties. All analyses were made on samples cleaned on a small Clipper Fan Mill and then handpicked.

Three reflectance spectrophotometers, Agtron Model M-500-A, Gardner Digital Difference Meter Model XL-10, and Hunter Color Difference Meter Model D 25 were used.

The Gardner and the Hunter color meters describe color in terms of three parameters: "L", a measure of lightness that varies from 100 for perfect white to zero for black; and two chromaticity dimensions, "a" and "b". Parameter a is a measure of redness when positive and greenness when negative (gray when zero). Parameter b is a measure of yellowness when positive and blueness when negative (gray when zero). The Agtron gives percentage of light reflected by the sample for green, blue, yellow, and red modes. The readouts for the three instruments are different. A 1 — 100% dial is read on the Agtron, the three Hunter color parameters are read from dials, and the Gardner L, a, and b values appear automatically on digital readouts.

Experienced inspectors rated the samples visually and assigned color scores from 1 (bright) to 10 (badly discolored) compared with barley samples used as standards.

Statistical analyses were performed on an IBM 360 computer using the Statistical Analysis System of the North Dakota State University Computer Center.

RESULTS AND DISCUSSION

Colors of the 121 barley samples were determined in duplicate on the three color meters. The mean differences and coefficients of variation for these data are shown in Table I.

Variation was low for the a and b readings of the Hunter and the yellow and red readings of the Agtron. The L reading of the Gardner was slightly less variable than the L of the Hunter and the green of the Agtron.

Correlation coefficients between the color parameters of the Gardner, Hunter, and Agtron color meters are shown in Table II. The Gardner and Hunter L parameters were significantly ($p > 0.01$) correlated. Each Agtron parameter was significantly correlated with either Gardner or Hunter L values. The Gardner and Hunter showed low correlation between their a and b values and with the Agtron parameters. On the basis of these data, we concluded that further readings of the a and b chromaticity parameters were not necessary because of their poor relation to barley color.

High correlation coefficients were found between the Gardner L, Hunter L, and the four Agtron values and visual color scores (Table III). The coefficients, which are higher between the averages of visual color scores and the instrument values than between the individual's readings and the instrument values, reflect the inconsistency between judges.

A stepwise procedure was used to obtain a multiple regression model for the average visual color scores and the color parameters of the three colorimeters.

TABLE I
Mean Difference and Coefficient Variation of Color Readings for the Gardner, Hunter, and Agtron Instruments (n = 121)

Instrument Parameter	Mean Difference	Coefficient of Variation
Hunter L	0.18	1.12
Hunter a	0.10	0.67
Hunter b	0.11	0.85
Gardner L	0.57	1.04
Gardner a	0.15	1.36
Gardner b	0.29	1.21
Agtron Green	1.00	1.22
Agtron Blue	0.58	1.04
Agtron Yellow	0.43	0.83
Agtron Red	0.23	0.70

TABLE II
Correlation Coefficients between Color Parameters of the Gardner, Hunter, and Agtron[a]

Color Parameters	Ga	Gb	HL	Ha	Hb	AG	AB	AY	AR
Gardner L (GL)	−0.60	0.39	0.95	−0.20	0.17	0.96	0.93	0.86	0.94
Gardner a (Ga)		−0.06	−0.54	0.51	0.22	−0.57	−0.52	−0.42	−0.43
Gardner b (Gb)			0.37	−0.03	0.62	0.34	0.18	0.30	0.42
Hunter L (HL)				−0.19	0.28	0.95	0.93	0.89	0.96
Hunter a (Ha)					−0.12	−0.19	−0.14	−0.20	−0.07
Hunter b (Hb)						0.20	0.12	0.28	0.33
Agtron Green (AG)							0.93	0.88	0.96
Agtron Blue (AB)								0.87	0.93
Agtron Yellow (AY)									0.90
Agtron Red (AR)									1.00

[a]5% Significance = 0.174; 1% significance = 0.228.

The maximized regression equation from this model was used to calculate an instrument color score from the color parameters.

Inclusion of the a and b values for the Gardner and Hunter instruments in the multiple regression model did not increase the magnitude of the regression coefficients (R^2) significantly (Table IV). Likewise, addition of the blue, yellow, and red color values for the Agtron did not increase the R^2 values significantly. Therefore, to obtain instrument color scores only the L values for the Gardner or Hunter and the green for the Agtron are necessary.

The regression equations for calculation of instrument color scores are:

Gardner Instrument Color (GIC) Score = $-0.577 \times GL + 33.616$
Hunter Instrument Color (HIC) Score = $-0.536 \times HL + 31.987$
Agtron Instrument Color (AIC) Score = $-0.128 \times AG + 12.284$

TABLE III
Correlation Coefficients between Instrument Color Parameters and Visual Color Scores[a]

Instruments and Color Parameters	VCA[b]	VCB	VCC	VCD	VCS[c]
Gardner L	−0.91	−0.83	−0.83	−0.81	−0.91
Gardner a	0.50	0.42	0.43	0.39	0.47
Gardner b	−0.28	−0.28	−0.31	−0.22	−0.30
Hunter L	−0.88	−0.83	−0.80	−0.78	−0.89
Hunter a	0.21	0.11	0.12	0.10	0.14
Hunter b	−0.17	−0.18	−0.17	−0.10	−0.17
Agtron G	−0.91	−0.85	−0.82	−0.81	−0.92
Agtron B	−0.88	−0.82	−0.80	−0.80	−0.89
Agtron Y	−0.82	−0.78	−0.76	−0.75	−0.84
Agtron R	−0.87	−0.82	−0.81	−0.79	−0.89

[a]5% Significance = 0.174; 1% significance = 0.228.
[b]VCA, VCB, VCC, and VCD = individual visual color scores.
[c]VCS = average visual color score.

TABLE IV
Multiple Regression Coefficients between Color Parameters and Average Visual Color Scores

Variables in Model[a]	R[b]
GL	0.834
GL Ga	0.843
GL Ga Gb	0.850
HL	0.794
HL Hb	0.802
HL Ha Hb	0.803
AG	0.837
AG AB	0.848
AG AB AY	0.850
AG AB AY AR	0.850

[a]GL Ga Gb = Gardner color parameters.
HL Ha Hb = Hunter color parameters.
AG AB AY AR = Agtron color parameters.

Instrument readings for color parameters are better correlated to instrument color scores than to visual color scores (Table V).

In a final experiment, 26 samples ranging in color from very light to heavily stained or discolored were selected to check the replicability of instrument color readings and visual color scores. Table VI shows the analysis of variance between replicates and operators for the Gardner, Hunter, and Agtron color meters. Replicate readings did not differ significantly with any of the three instruments. Correlation coefficients between operators for instrument readings for Gardner L, Hunter L, and Agtron green were higher than between individual visual color scores (0.74 to 0.90). This indicates more variation between visual scoring than between operators of color instruments. The Gardner had lower variability between operators than the Hunter or Agtron color meters.

The regression equations for instrument color scores *vs.* visual color scores were used to develop a chart for converting instrument readings to barley color scores (Table VII). Ranges of barley color scores from 1 to 10 were introduced into the equations, and corresponding ranges for color parameters for each instrument were calculated.

PROPOSED METHOD

From the data obtained in this research, we propose the method outlined

TABLE V
Correlation Coefficients between Instrument Color Parameters, Instrument Color (IC) Scores, and Average Visual Color Scores (VCS)[a]

Color Parameters	GIC	HIC	AIC	VCS
Gardner (L)	−1.00	−0.949	−0.964	−0.913
Hunter (L)	−0.949	−1.00	−0.954	−0.891
Agtron (G)	−0.964	−0.954	−1.00	−0.915
GIC		0.949	0.964	0.908
HIC			0.954	0.872
AIC				0.896

[a]5% Significance = 0.174; 1% significance = 0.228.

TABLE VI
Analysis of Variance and Correlation Coefficients of Gardner, Hunter, and Agtron Parameters (n = 26)

	F-Values		r-Values
Source	Replicates	Operators	Operators[a]
Gardner L	0.0984	0.4714	0.978
Hunter L	0.0018	21.6368**	0.912
Agtron G	0.0024	4.0898*	0.977
Agtron B	0.1710	7.1760**	0.953
Agtron Y	0.0190	22.504**	0.890
Agtron R	0.0002	24.3735**	0.867

[a]5% Significance = 0.374; 1% significance = 0.478.

below for measuring barley color with a Gardner Digital Color Difference Meter.

Instruments and Materials

1. Gardner Digital Color Difference Meter, Model XL 10 CDM. Gardner Laboratory, Inc., Bethesda, MD 20014.
2. Brown calibration tile, Hunter Laboratory D 33C-330. Hunter Associates Laboratory, Inc., Fairfax, VA 22030.
3. Sample cell. Glass plate with 4-1/4 in. diameter ring attached.
4. Small soft brush.

Operating Procedures

1. Remove small area plate from top of machine.
2. Remove two thumb screws on either side of the machine and lift the lid up and back. Carefully dust all lenses with the brush. Replace the lid and screws.
3. Turn the instrument on and let it warm up for the required time (30 min) with the brown calibration tile in place over the test aperture. (Use of a standard similar in color to the test samples stabilizes the responses of the photoelectric cells and improves precision and accuracy of color measurements.)
4. Place beam switch on large. If the readout tends to wander, additional warm-up is needed.
5. Standardize the instrument against the brown calibration tile. Push in one at a time the L, a, and b buttons. With control knobs adjust the readout for each setting (L, a, and b) to the number printed on the tile. Repeat this procedure until the readouts do not wander from the L, a, and b values.
6. Pour sample into sample cell and uniformly flatten it with the hand. Remove the tile and place the cell in the instrument in such a manner that the photoelectric cells are always energized. No light must pass through the prepared sample. Note the orientation of the sample cell.
7. Read the L value and record on data sheet.
8. Turn sample cell 90 degrees and take a second reading and record.
9. Recheck calibration standard every 20–30 samples or every hour.
10. Convert the average L value to barley color score using the conversion chart.

TABLE VII
Chart for Converting Instrument Readings to Barley Color Score

Gardner L	Hunter L	Agtron Green	Barley Color Score
over–55.7	over–56.9	over–84.2	1
53.9–55.6	55.0–56.8	76.4–84.1	2
52.2–53.8	53.1–54.9	68.6–76.3	3
50.5–52.1	51.3–53.0	60.8–68.5	4
48.7–50.4	49.4–51.2	53.0–60.7	5
47.0–48.6	47.6–49.3	45.2–52.9	6
45.3–46.9	45.7–47.5	37.4–45.1	7
43.5–45.2	43.8–45.6	29.6–37.3	8
41.8–43.4	42.0–43.7	21.8–29.5	9
under–41.7	under–41.9	under–21.7	10

Recommendations

1. Keep the brown calibration tile clean and avoid scratching or abrading the surface.
2. Keep the optics of the instrument clean.
3. Cover instrument when not in use.

CONCLUSIONS

From these evaluations we concluded that the Gardner, Hunter, and Agtron instruments can be used to measure barley color. A preference is shown toward the Gardner because of its better reproducibility, and ease and speed of operation.

Only one color parameter (the L value for the Gardner or Hunter and the green for the Agtron) is necessary to determine barley color. Instrument color readings can be converted to barley color scores through a converting chart or calculated by the appropriate regression equations.

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Literature Cited

1. CHRISTENSEN, C. M. Storage of cereals grains and their products, p. 176. American Association of Cereal Chemists: St. Paul, Minn. (1974).
2. KNEEN, E. Barley microflora. Friend or foe? Proc. Irish Maltsters Conf., p. 51 (1963).
3. MALT RESEARCH INSTITUTE. A study of the influence of weather on the suitability of barley for malting and brewing. Wallerstein Lab. Commun. Abstr. 20(68): 74 (1957).
4. PEPPER, E. H. The microflora of barley kernels. Ph.D. thesis. Michigan State University (1960).
5. AMAHA, M., KITABATAKE, K., NAKAGAWA, A., YOSHIDA, J., and HAVADA, T. Gushing inducers produced by some mould strains. Eur. Brew. Conv., Proc. Congr. 14th, Salzburg, 1973, p. 381.
6. ANDERSON, K., GJERTSEN, P., and TROLLE, B. The microflora of barley and its effects on wort and beer. Brew. Dig. 42(8): 76 (1967).
7. GJERTSEN, P. Gushing in beer, its nature, cause and prevention. Brew. Dig. 42(5): 80 (1967).
8. U.S. DEPARTMENT OF AGRICULTURE. Official grain standards of the United States. U.S. Government Printing Office: Washington, D.C. (1964).
9. GILLIS, J. A. The Agtron. Cereal Sci. Today 8: 40 (1963).
10. HUDSON, J. R. Measurement of color in wort and beer. J. Inst. Brew. 75(2): 164 (1969).
11. PATTON, J., and DISHAW, M. Flour color evaluation with the green Agtron. Cereal Sci. Today 13: 163 (1968).
12. STONE, I., and MILLER, M. C. The standardization of methods for the determination of color in beer. Wallerstein Lab. Commun. 25(87): 43 (1962).
13. REINER, L. A simplified photometric procedure for the determination of wort color for selection of hybrid barley varieties suitable for brewing. (Abstr.) J. Inst. Brew. 73(6): 587 (1967).
14. MATZ, S. A., and LARSEN, R. A. Evaluating semolina color with photoelectric reflectometer. Cereal Chem. 31: 73 (1954).
15. WALSH, D. Measurement of spaghetti color. Macaroni J. 51(4): 20 (1970).
16. MALTING BARLEY IMPROVEMENT ASSOCIATION. Condensed annual report, ed. by A. J. Lejeune. Master Brew. Tech. Quart. 6(2): 107 (1969).
17. POMERANZ, Y. Evaluation of malting barley. Master Brew. Tech. Quart. 8(4): 191 (1971).
18. BRANDON, A. L. Determination of color in beer, wort and brewing materials. Amer. Soc. Brew. Chem., Proc. 1957, p. 77.
19. CLYDESDALE, F. M. Color and haze measurements of beer. Brew. Dig. 48(10): 46 (1973).

20. SHUEY, W. C., and SKARSAUNE, S. K. The relation between flour mineral content and flour color reflectance values. Cereal Sci. Today 18: 229 (1973).
21. SUNESON, C. A., and DICKSON, A. D. Hybrid barleys are coming. Master Brew. Tech. Quart. 3(3): 185 (1966).
22. SKARSAUNE, S. K., BANASIK, O. J., and WATSON, C. A. The measurement of barley kernel color. Amer. Soc. Brew. Chem., Proc. 1971, p. 5.

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