Determination of Bran Contamination in Wheat Flours Using Ash Content, Color, and Bran Speck Counts[1]

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ABSTRACT

Cereal Chem. 76(6):957–961

A fast new method based on image analysis, ScanPro Speck Expert (SPX), to determine the bran contamination in wheat flour was studied and compared with existing methods (air-oven, ash, and color measurements) using an Agtron color meter and a Minolta chromameter. Twenty-one hard red winter wheat flour samples with ash contents of 0.30–0.58% were collected from the Kansas State University pilot mill and used for this study. Intrinsic variability in the flour sample because of randomness of bran speck orientation and distribution in the sample holder could result in variation in the speck count. Simple and multiple linear regression analyses showed that estimation of flour ash content from the SPX results (R^2 = 0.91) would be more accurate than the results from color measurements (R^2 = 0.66 [Agtron color meter] and 0.74 [L^*]). The added capability of SPX image analyzer to not only count the number of bran specks but also to measure their areas probably increases the accuracy of determining the bran contamination in wheat flour by image processing.

The objective of wheat flour milling is to separate endosperm from the bran and germ as cleanly as possible and reduce the endosperm into flour. The purity of wheat flour traditionally has been expressed as ash content. Ash content, inorganic material left after incineration, increases from the center to the outer layers of the wheat kernel (Hinton 1959). Lower ash content in flour indicates less contamination with wheat bran and germ.

Ash content is generally not known to be a good indicator of the baking quality of flour (Wichser and Shellenberger 1948). But because of its positive correlation with flour color, a convenient quality testing procedure, and (more significantly) firmly established preferences, many bakers still insist on using ash content as a specification restriction in determining a flour grade.

Several researchers have conducted experiments to estimate ash content using wheat characteristics. Kim et al (1995) applied multiple linear regression analysis to estimate the ash content of flour using physical, chemical, and experimental milling results of commercial wheat blends. They reported that coefficients of determination (R^2) were 0.74 and 0.73 for hard red winter (HRW) wheat and a blend of HRW and hard red spring (HRS) wheats, respectively.

One of the best applications of ash content is in evaluating milling performance by constructing cumulative ash curves. Shellenberger (1965) referred to the ash curve as one of the major advances in the control of the flour milling process. The cumulative ash curve shows the relationship between cumulative flour ash content and cumulative flour yield. Any sudden change in the cumulative ash curve may indicate worn corrugation and improper adjustment in rolls and purifiers (Posner 1991). However, the main purpose of the cumulative ash curve is to determine yields of patent, first clear, and second clear flours at a cutoff point of ash content for a particular product. Based on predetermined information, a flour mill selects and blends several flour streams for a maximum amount of flour at a specified ash content (Shellenberger and Ward 1967). Flores et al (1991) showed that the cumulative ash curve can be modeled as a function of the wheat characteristics. The curves also can be applied through the use of a computer simulation model to evaluate the economic effect of using different wheats for a finished product (Flores et al 1991).

Flour milling is a continuous operation. A rapid method to determine the ash content is necessary to make quick decisions about flour stream selection for maximum flour production and profit. The traditional method of determining the ash content, the air-oven method, is time-consuming, so it is not a suitable test for the stream selections during the milling operation, but rather is used mainly for final quality control.

Most flour mills still rely on the experience of a miller to select the flour streams based on the slick test. This test is done by manually pressing samples on a tray using a thin-bladed paddle (the slick) and inspecting the color or dress of samples (Posner and Hibbs 1997). The dark bran specks can be easily identified visually and indicate to some extent the degree of purity of a flour stream. However, the test is subjective and totally dependent on human judgment. To reduce this subjective aspect of color measurement, instruments such as the Kent-Jones and Martine flour color grader and the Agtron color meter are used. Both instruments use the photoelectric method which measures the degree of reflectance of a certain wavelength. Gillis (1963) stated that an Agtron color meter using a blue filter (light transmission at 436 nm) is sensitive to bleach; thus it was not recommended to replace the ash content measurement. However, he concluded that by using a green filter (546 nm) insensitive to bleach, the Agtron color reading could be converted accurately to ash content. Shuey and Skarsaune (1973) found a high linear relationship between flour ash content and color reading from the Agtron color meter (R^2 = 0.86). However, a regression equation was valid for only one wheat mix. They concluded that different regression equations were necessary for different wheat mixes to determine an accurate estimation of ash content. By recommendation of the CIE (1986), tristimulus (L^*, a^*, and b^*) color coordinates have been evaluated for flour refinement measurements (Allen et al 1989, Symons and Dexter 1991). Symons and Dexter (1991) found that the L^* value (brightness) of flour was highly related to pericarp and aleurone fluorescence. They also found that a^* and b^* values were sensitive to moisture content and flour particle size, whereas L^* values were slightly sensitive to particle size only. Oliver et al (1992) showed that a linear relationship existed between Kent Jones color measurements (KJ) and L^* values (R^2 = 0.72). A multiple linear regression analysis between KJ and all three tristimulus values (L^*, a^*, and b^*) showed higher R^2 (0.81). But a higher R^2 (0.85) was observed between ash content and L^*. However, R^2 decreased to 0.84 with multiple linear regression using the three tristimulus values in his study.

Image analysis has been applied to the cereal processing industry for almost two decades. Particle-size measurement of a component or whole kernel is the most popular usage of image analysis (Symons and Fulcher 1988, Keefe 1992, Bechtel et al 1994, Zayas et al 1994). Most recently, Harrigan and Bussmann (1998) applied image analysis technology to count dark specks in semolina. A limited number of specks in semolina is a quality factor often

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Publication no. C-1999-1007-05R.

specified by customers. Harrigan and Bussmann (1998) compared a traditional manual counting method with a digital counting method using ScanPro Speck Expert image analysis technology (SPX, Maztech Micro Vision Ltd.). They described the digital image processing of SPX as a process whereby the camera acquires an image that is divided into its smallest picture elements or pixels. A gray value is assigned to each pixel based on brightness, plotted on a histogram, and analyzed according to a specific model or algorithm. After comparing the manual and digital counting methods, they concluded that when many specks are present in semolina, a manual count tends to record fewer specks than a digital count. They indicated that the digital count can be calibrated to fit the manual count using gray levels and particle-size settings. They also reported a high R^2 (0.99) between manual and digital speck counts in corn grits.

This study was undertaken to evaluate existing techniques and image processing for determining the bran contamination in wheat flour. Specific objectives were to 1) evaluate the repeatability and variability of a commercial image analysis unit for bran speck counting; 2) determine the bran contamination in wheat flour using various methods, including ash content, color, and bran speck counts; and 3) compare and establish the relationships among the methods tested.

MATERIALS AND METHODS

Flour Samples

Samples of 56 streams of HRW wheat flour were collected from two wheat blends, 23 flour streams each, from the Kansas State University (KSU) pilot mill. To represent a practical range of ash contents (0.3–0.58%) in the commercial patent and straight-grade flours, 15 flour samples with ash contents of 0.30–0.51% were selected from the 56 flour streams. Five more flour samples with ash contents of 0.43, 0.49, 0.53, 0.55, and 0.58% were prepared by blending two different flour streams. The straight-grade flour with ash content of 0.45% was also selected for the experiment. Therefore, a total of 21 flour samples were used in this study.

TABLE I
Setup Parameters of an SPX Image Analyzer

	Mfg's Recommended Setting (SET1)	Selected Setting (SET2)
Grey levels		
Global	210	240
Black	200	230
Brown	255	255
Particle size range (μm)		
Minimum	156	56
Maximum	1,944	506

Measurements of Ash, Moisture, Particle Size, and Color

The flour moisture and ash contents were determined by Approved Methods 44-19 and 08-03, respectively (AACC 1995). The geometric mean diameter of the flour streams was determined by procedure S319.2 of the ASAE (1996). The colors of flour samples were tested with an Agtron color meter (model M-45-D) and a Minolta chromameter (model CR-310). The Agtron color was determined according to the Approved Method 14-30 with major modifications including 1) using the flour samples without adding water, and 2) setting the Agtron certified calibration disks 68 and 97 for 0 and 100%, respectively. The Minolta chromameter was calibrated with a standardized disk provided by the manufacturer and set up for tristimulus (L^*, a^*, and b^*) color coordinates. All ash contents in this study are expressed on a 14% moisture basis.

Image Analysis

An SPX image analyzer originally developed for speck counting in semolina from durum wheat was used in this study. The SPX image analyzer was designed to count black and brown specks by assigning them a gray level value within the range of 0 (black) to 255 (white). For flour samples, the manufacturer recommended the global gray level as 210, the gray level as 200, and the initial particle-size range as 156–1,944 μm. During the initial test of SPX image analysis, some of these setup parameters seemed unsuitable for measuring wheat flour because many bran specks appeared not to be included in the counts. As the gray scale level increased, and as the minimum particle size decreased, more bran specks were available for the count. Therefore, a new set of gray levels and bran particle size was selected to compare with the results from the manufacturer's recommended setting.

After several trials, the global and maximum black gray levels were set at 240 and 230, respectively. The minimum brown gray level did not change. No brown particles were counted because the value of the brown gray level was higher than that of the global

TABLE II
Results from Repeatability and Variability Studies of an SPX Image Analyzer with Wheat Flour Samples Using SET1[a]

	Speck Counts			Standard Deviation		Coefficient of Variation (%)		ANOVA[c]
Samples[b]	Average	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	*F*-value
1	6	3	7	0	1.00	0	14.29	33.2
2	10	8	12	0.58	1.15	7.53	11.11	19.5
3	34	28	28	0.58	2.52	1.53	7.52	24.8
4	3	1	5	0	0.58	0.00	43.30	55.5
5	45	37	53	0	3.51	0.00	9.41	42.0
6	7	6	8	0.33	2.33	5.26	30.43	1.1
7	13	12	15	0	0.58	0	4.56	42.0
8	24	19	26	0	2.08	0	7.91	18.7
9	10	8	11	1.53	2.65	13.5	33.07	2.3
10	21	16	31	1.00	2.52	3.23	16.06	76.4
11	21	17	27	1.00	2.65	3.70	15.56	26.3
12	47	42	54	0.58	3.61	1.27	6.68	22.5
13	53	46	60	1.53	3.06	3.34	5.06	26.9
14	95	86	104	2.31	5.20	2.70	5.00	15.5
15	103	78	127	4.00	5.29	3.56	6.78	83.2
16	131	123	142	7.51	12.1	5.37	9.47	3.6
17	152	137	162	3.79	9.24	2.33	5.87	11.2
18	104	95	118	2.65	6.66	2.67	7.03	20.5
19	132	109	130	1.53	5.03	1.18	4.60	23.4
20	146	132	161	1.15	3.51	0.72	2.65	105.5
21	164	138	190	2.08	6.81	1.51	4.12	68.8

[a] SET1 = manufacturer's recommended setting.
[b] Flour samples are in order of ash content.
[c] Analysis of variance. F = critical value 10.9 at 1% significant level.

gray level. The minimum particle size of bran was set to 56 μm (the size of a pixel 56 × 56 μm), and the maximum bran size was set to 506 μm. Speck counts were reported as specks/103.2 cm^2 (16 $in.^2$). A summary of the manufacturer's initial setting (SET1) and the selected setting (SET2) is shown in Table I.

Experimental Design and Statistical Analysis

The study of repeatability and variability of SPX bran speck count using both SET1 and SET2 was divided into two parts: 1) determining the variability within the measurements, and 2) determining the variability among the samples. For the first part, one aliquot of flour sample (≈70 g of flour) was taken out of a plastic bag and poured into a sample holder. Then triplicate measurements were done without removing the holder from the SPX image analyzer. The flour sample was dumped back into the plastic bag and mixed, and then another aliquot of sample was taken from the same bag and measured three times with the SPX image analyzer. This procedure was repeated for three aliquots for each flour sample to evaluate variability among samples. A total of nine readings were measured for each flour sample under each setup parameter.

Maximum and minimum speck counts, mean, standard deviation, and coefficient of variation (CV) were calculated from each aliquot to study the variability within the measurements. Analysis of variance (ANOVA) was used to study the variability among the samples.

Simple and multiple linear regressions were performed to study the relationship among the methods for determining bran contamination of wheat flour. Independent variables in the simple linear regressions were the speck counts recorded from SET1, speck counts recorded from SET2, Agtron color meter readings, and *L**

TABLE III
Results from Repeatability and Variability Studies of an SPX Image Analyzer with Wheat Flour Samples Using SET2[a]

Samples[b]	Speck Counts			Standard Deviation		Coefficient of Variation (%)		ANOVA[c]
	Average	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	*F*-value
1	140	136	145	0.6	3.0	0.43	2.07	16.80
2	502	496	507	8.0	39.4	1.61	7.76	0.16
3	836	734	932	10.0	48.0	1.36	5.14	23.85
4	91	83	102	2.6	5.1	3.04	5.05	21.55
5	1,757	1,585	1,980	77.6	115.9	3.92	6.79	13.43
6	357	344	375	1.2	5.1	0.31	1.46	57.93
7	277	257	311	1.5	13.1	0.58	4.22	40.82
8	660	651	673	2.9	10.6	0.44	1.63	6.86
9	1,290	1,152	1,467	4.0	44.2	0.32	3.84	98.60
10	1,341	1,307	1,388	18.2	42.7	1.40	3.10	4.20
11	1,602	1,518	1,697	36.8	66.3	2.32	4.16	10.00
12	2,744	2,606	2,905	52.3	86.6	1.92	3.32	14.01
13	3,504	3,236	3,677	64.3	98.0	1.99	2.72	23.17
14	1,954	1,911	2,028	4.5	33.3	0.22	1.73	19.45
15	5,329	5,052	5,535	11.0	62.4	0.20	1.16	97.56
16	6,657	6,469	6,896	26.1	101.3	0.40	1.51	20.48
17	6,658	6,203	7,341	57.9	110.1	0.93	1.50	153.15
18	1,967	1,795	2,054	17.0	31.0	0.83	1.51	123.05
19	6,047	5,701	6,353	103.4	152.6	1.70	2.68	18.06
20	6,241	6,134	6,454	77.8	185.8	1.21	3.03	6.55
21	6,728	6,418	7,182	46.7	78.6	0.71	1.22	130.49

[a] SET2 = selected setting.
[b] Flour samples are in order of ash content.
[c] Analysis of variance. *F* = critical value 10.9 at 1% significant level.

TABLE IV
Bran Contamination in Wheat Flour Samples

Sample[a]	Ash[b] (%)	Agtron	Tristimulus Parameters (%)		
			*L**	*a**	*b**
1	0.30	82	99.5	–0.01	0.52
2	0.31	77	98.8	–0.23	1.98
3	0.31	77	99.1	–0.20	2.07
4	0.32	82	99.4	0.02	0.40
5	0.32	73	99.9	–0.61	3.42
6	0.33	80	99.3	0.13	–0.17
7	0.34	83	99.5	0.02	0.00
8	0.34	77	99.1	–0.14	0.61
9	0.35	74	98.6	0.27	0.16
10	0.36	74	98.5	0.27	0.22
11	0.37	73	98.3	0.13	1.03
12	0.40	70	98.1	–0.17	1.50
13	0.43	69	98.1	0.06	1.41
14	0.45	73	98.4	1.04	–1.92
15	0.47	66	97.6	0.08	1.67
16	0.49	64	97.3	–0.16	2.27
17	0.50	64	97.4	–0.16	2.19
18	0.51	77	98.8	0.18	0.05
19	0.53	65	97.5	0.07	1.78
20	0.55	65	97.3	–0.02	1.89
21	0.58	64	97.3	0.03	1.81

[a] Flour samples arranged in ash content order.
[b] 14% mc.

values from tristimulus color readings. The multiple linear regressions were performed using all three values (L^*, a^*, and b^*) from tristimulus color readings as the independent variables. All statistical analyses were performed using Quattro Pro version 7 (Corel, Ottawa, ON, Canada).

RESULTS AND DISCUSSION

Tables II and III show analyses results using SET1 and SET2, respectively. These results show the repeatability and variability studies using all 21 flour samples. The standard deviation range obtained from 21 flour samples using SET1 was 0–12.1. The majority (14 of 21) of the flour samples had standard deviations <5.0. Five flour samples had CV values <5.0%, but three flour samples (4, 6, and 9) had CV values >30%. The overall average bran speck count increased 42-fold from SET1 to SET2, so the standard deviation range obtained from SET2 was much wider (0–185.8). The lowest increment of bran speck counts from SET1 to SET2 was observed for flour sample 18 (19-fold), whereas the highest was observed for flour sample 9 (129-fold). The CV range from SET2 was 0–7.8%. Seventeen flour samples had CV values <5%, and the highest CV was observed for flour sample 2. This analysis showed that bran speck count from SET2 had much less variability than that from SET1 because of its wide range in speck counts. Tables II and III also show *F*-values calculated from the ANOVA. The hypothesis of ANOVA was that the mean of bran speck count of all three aliquots from the same flour sample would be the same at the 1% significance level. The results showed that the means from three aliquots of the same flour were not the same for 18 of 21 flour samples with SET1 and for 16 of 21 flour samples with SET2. This is an indication that measurements among samples from the same flour sample have a wide range of variation because of the intrinsic variability associated with a granular sample. Because of the randomness of bran speck orientation and distribution when samples were placed in the holder, a different image was produced and a different number of specks was counted for each measurement.

These results are characteristic of image analysis studies. Gillis (1963) discussed several methods of sample preparation and presentation for an Agtron color meter where the slightest variations would give irregular results. Other possible sources of variation might be the cleanness of sample holder and scanning window and the stability of voltage source in the unit.

Ash contents, Agtron color readings, and tristimulus measurements of flour samples are shown in Table IV. As the ash content increased from 0.30 to 0.58%, the speck counts with SET1 increased from 3 to 164. Flour samples 2 and 3 had the same ash content (0.31%), but sample 3 had threefold greater speck counts than sample 2 using SET1. Similarly, sample 5 had a 15-fold greater speck count than sample 4 using SET1 with the same ash content (0.32%). The Agtron color test also indicated that samples 4 and 5 had different color readings (82 and 73, respectively) but the same ash content. Both the speck count and the Agtron color test showed that sample 4 had less bran contamination than sample 5. However, L^* values from the tristimulus color test implied that sample 4 had slightly higher bran contamination than sample 5. The speck count recorded with SET2 also showed a similar tendency: different numbers of specks counted for two flour samples with the same ash content.

Flour samples from the sizing system (4, 6, and 8) had relatively lower speck counts than samples from the other flour streams with similar ash content. This phenomenon may be explained by the particle-size distribution of the flour streams (data not shown). The largest particles of most flour streams were overs of U.S. sieve 50 and 70 (with opening sizes of 0.297 and 0.210 mm, respectively). However, the largest particles of samples 4, 6, and 8 were the overs of U.S. sieve 30 (0.600 mm), even though they constituted a small amount (0.002–0.04%) of the total weight. This suggests that a few large bran particles could have contributed to high flour ash content.

Simple and multiple regressions among ash content, bran speck counts, and color readings were evaluated, and their coefficient of determinations (R^2) are shown in Table V. R^2 between ash content and speck count using SET1 and SET2 were high (0.91 and 0.80, respectively). Ash content and Agtron color measurement had a lower R^2 (0.66) than that (0.83) reported by Shuey and Skarsaune (1973). The flour samples they used had a wider range of ash content (0.28–0.77%) than those used in this study, which could have contributed to the higher R^2. Ash content and L^* also had a lower R^2 (0.73) compared with the results (0.85) from Oliver et al (1992). The flour samples in that study were obtained from Buhler and Quadrumat Jr. experimental and commercial mills. The higher ash content flours produced from the Quadrumat Jr. experimental mill would have widened the range of ash content of flours in their study and could have contributed to the higher predictability. Multiple regression analysis between ash content and tristimulus parameters (L^*, a^*, and b^*) were slightly improved ($R^2 = 0.74$).

The R^2 values obtained from simple and multiple regression analysis between speck count with SET1 and results from tristimulus color tests were 0.67 and 0.69, respectively. The R^2 improved to 0.84 (simple) and 0.89 (multiple) for speck counts using SET2 and tristimulus color values. The R^2 of simple regression analysis between Agtron color meter and tristimulus color readings was 0.84, but the R^2 of multiple regression analysis between parameters was the highest (0.93) among the observations.

TABLE V
Coefficient of Determination (R^2) for Regression Analysis Among Several Analytical Parameters (n = 21)

Parameter	Ash[a] (%)	SET1	SET2	Agtron
Speck counts				
SET1	0.91			
SET2	0.80	0.86		
Agtron	0.66	0.71	0.90	
Tristimulus				
L^*	0.73	0.67	0.84	0.84
$L^*+a^*+b^*$	0.74	0.69	0.89	0.93

[a] 14% mc.

CONCLUSIONS

Image analysis, along with measurement of ash content and color readings using an Agtron color meter and tristimulus parameters, was performed to determine the bran contamination in wheat flour. The repeatability and variability studies of an SPX image analyzer showed that sample preparation plays a very important role in obtaining consistent results. The color and bran speck counts are rapid methods of determining the bran contamination when compared with the traditional air-oven method for ash content. Simple and multiple linear regression analysis showed significant correlations between flour ash content and the number of bran specks. Based on regression analysis, estimating ash content using bran speck counts would be more accurate than estimation with flour color. Not only the number of bran specks, but also size of the bran particle probably influence the flour ash content. Including the size of bran specks probably improves the estimation of ash content. Use of SPX image analysis in a flour mill as an ash content indicator should be preceded by the corresponding calibration based on the flour streams as in this study.

ACKNOWLEDGMENTS

We express sincere gratitude to Kate Harrigan and Stefan Bussmann at Maztech Micro Vision Ltd. for providing the ScanPro Speck Expert. We also wish to thank Yufeng Mao, graduate research student, for her help during this study. Use of ScanPro Speck Expert in this research does not constitute an endorsement of the product.

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[Received January 25, 1999. Accepted July 18, 1999.]