Grading Peanut Butter Using Video Image Analysis Techniques[1]

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ABSTRACT

A video image analysis system was designed to quantitatively measure the amount of specks and the color of peanut butter samples for grade purposes. The video image of a peanut butter surface 5.8 cm by 5.8 cm was captured and converted into 384 by 384 picture elements (pixels). The intensity of each of the 147,456 pixels was classified into one of 256 shades of gray from zero for black to 255 for white. The percent of total pixels that represented specks was defined as the speck index. The aveage shade of gray of all 147,456 pixels was defined as the color index. The speck and color indices were computed for 52 peanut butter samples that had been graded by experienced Agricultural Marketing Service (AMS) inspectors. The speck and color indices were both in good agreement with the AMS speck and color classifications assigned to the samples by the AMS inspectors.

Key Words: Peanut butter, grading, video image analysis, defects, color.

The Agricultural Marketing Service (AMS), United States Department of Agriculture (USDA) inspects peanut butter for four grade factors: (a) defects, which is a measure of the amount of dark specks in the peanut butter; (b) color, which primarily reflects the degree of roast; (c) consistancy or spreadability; and (d) flavor and aroma (1,2). Each of the four grade factors are numerically scored and each factor then receives a grade of A, B, or S (generally referred to as substandard or SSTD by AMS) depending upon the numerical score.

The grade factor concerned with defects (specks) is numerically scored by visually comparing the specks in the peanut butter samples with photographic guides called A and B which are photographs of two peanut butter samples. Guide A has fewer specks than guide B. If a peanut butter sample has fewer specks than guide A, the sample is numerically scored from 27 to 30 and given a grade of A for defects. Samples with more specks than guide A but fewer than guide B are scored from 24 to 26 and given a grade of B. If the sample has more specks than guide B, the sample is scored from zero to 23 and classified as S. Since the number, size, and degree of darkness of specks can vary widely from sample to sample, numerical scores can be difficult to assign by visually comparing samples to the photographic guides.

The second grade factor, color, is numerically scored by comparing the color of the peanut butter sample to a set of USDA color standards. The USDA color standard has a range of four "acceptable" colors. If the color of a sample is within the acceptable range, the sample is scored from 18 to 20 and given a grade of A for color. Samples with a "typical" peanut butter color but outside the range of the acceptable colors are scored 16 or 17 and given a grade of B. When samples fails to meet the above requirements, they are scored from zero to 15 and given a grade of S for color.

Because of the subjectivity associated with visually determining the numerical score for defects (and to a lesser extent for color), AMS requested that equipment and procedures be developed to measure the amount of specks in peanut butter samples. The Agricultural Marketing Service (AMS) also indicated that it would be desirable if the same equipment could objectively measure the color or degree of roast of peanut butter samples.

With recent technological advances and cost reductions in video imaging equipment, video image analysis techniques offer an objective approach to measuring defects and possibly color (3,4,5 and 6). The purpose of this study was to develop video analysis techniques that can be used to measure either defects or color.

Materials and Methods

Equipment - A schematic diagram of the video image system used in this study is shown in Fig. 1. It is a hardware and software video system sold by Chorus Data Systems (P. O. Box 370, Merrimack, NH, 03054) that can digitize a video image for analysis by an IBM or compatible microcomputer. The system consists of a RCA black and white video camera, a capture/digitizer board, a Number Nine Revolution graphic board, a black and white 800 line resolution Panasonic monitor, and related software needed to manage and process the di-

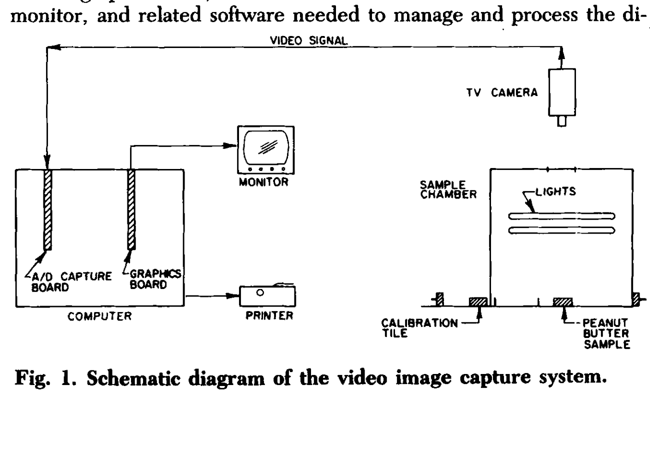

Fig. 1. Schematic diagram of the video image capture system.

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gitized image data. The capture/digitizer and graphic boards occupy full length slots of an IBM XT computer.

The capture/digitizer board has a high speed eight bit A/D converter that can convert a full video image frame into a maximum of 512 horizontal and 480 vertical picture elements (pixels) for a total of 245,760 pixels. The system can be programmed to use fewer pixels if necessary. For each pixel, the intensity of the video signal is converted into one of 256 shades of gray or 256 gray scale values from zero for black to 255 for white. As a result, the video image is converted into 245,760 bytes of data with each byte being an integer value from zero to 255. It takes approximately 0.3 seconds to capture, digitize, and store the 245,760 gray scale values in computer memory. Once the digitized image is stored in memory or on a magnetic disk, the data can be processed and analyzed like any data file.

A light-tight chamber (51 cm x 51 cm x 41 cm tall) with two 40 watt circular (46 cm diameter) fluorescent bulbs was constructed to uniformly illuminate a calibration tile or a peanut butter sample for image capture. A sliding sample holder was built into the side of the chamber so peanut butter samples could be easily positioned in the bottom center of the chamber. The video camera was mounted over a 6.1 cm diameter port in the top center of the chamber through which the peanut butter sample image was captured. For system calibration, a light brown ceramic tile about 11.2 by 11.2 cm square was also mounted on the sliding sample holder. When the sample holder was moved to one extreme position to remove or load a peanut butter sample, the ceramic tile was positioned under the camera. While the video camera was viewing the ceramic tile, the light intensity in the box could be adjusted by adjusting the A/C line voltage to the fluorescent bulbs with a variable transformer so that the averaged composite video signal from the camera tube was always 100 millivolts. The averaging circuit consisted of a filter (50 μf capacitor and 10 K ohm resister) along with a rectifier.

Sample Preparation - The AMS collected a sample from each of 52 lots of peanut butter from seven different manufacturing plants. The samples were stored at 10 C when not being used. A 125 g portion of peanut butter from each sample was placed into a 12.7 cm diameter clear plastic petri dish. The dish with the 125 g portion was then placed into a convection oven controlled at 50 C for 45 min. The peanut butter flowed to a uniform depth over the bottom of the petri dish. No voids were observed when the peanut butter was cooled and viewed through the bottom of the dish. Each dish was coded to maintain the identity of the samples.

The system was first calibrated with the ceramic tile as described above. The sample dish was placed upside-down on the sample holder and positioned under the camera where the image was captured. The dish was placed upside down because the smooth interface between the peanut butter and the bottom of the dish eliminated any shadows on the sample surface. An image approximately 5.8 by 5.8 cm in area was captured. The area was represented by 384 by 384 or 147,456 pixels. The 147,456 gray scale values were stored in a file for future analysis. It took approximately 25 sec. to calibrate, capture, and store the image data. A total of 52 files, one for each sample, was stored on a magnetic disk.

AMS Grade Classification - Two experienced AMS inspectors examined each of the 52 peanut butter samples and gave a consensus determination for defects and for color. For defects, each sample was classified into five possible categories. Using the two photoguides discussed earlier, the samples were classified as A, B, or S. In addition, if a sample fell between grades A and B or between grades B and S the sample was classed as AB or BS, respectively. For color, each sample was classified into nine possible categories using the four acceptable colors in the USDA color standard discussed earlier. The color strips varied from a light brown for color strip 1 to a darker brown for color strip 4. If the color of a sample did not exactly match one of the above four strips, then the sample was classified into an intermediate color category. The nine categories were 0.5 (lighter than 1), 1, 1.5, 2, 2.5, 3, 3.5, 4 and 4.5 (darker than 4).

Speck and Color Index -Software was developed to compute the distribution of pixels according to their gray scale values for each captured image (sample). A typical pixel GS distribution is shown in Fig. 2. From the pixel distribution the average gray scale (AGS) of all 147,456 pixels was computed from the frequency distribution using Eq. 1.

$$AGS = \sum_{i=0}^{255} (n(i) \cdot i) / \sum_{i=0}^{255} n(i) \qquad (1)$$

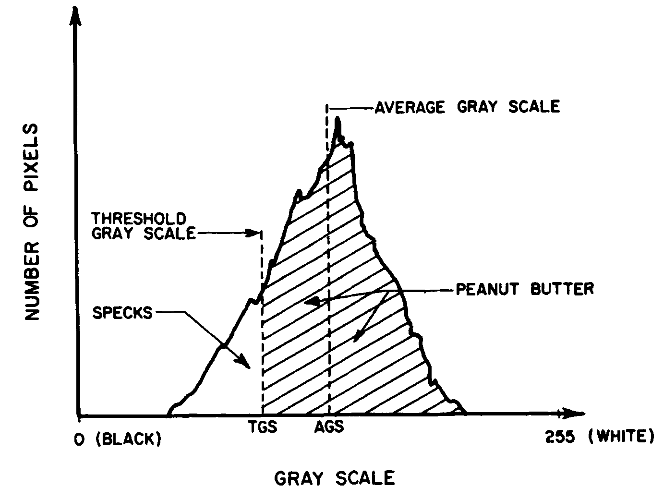

Fig. 2. Typical frequency distribution showing the number of picture elements (pixels) at various shades of gray.

where n(i) is the number of pixels with a gray scale of i (i is an integer from zero to 255). The AGS is a measure of the intensity, not the true color, of the peanut butter sample. However, the AGS was defined as the color index and was compared to the consensus color classification assigned to the sample by the two AMS inspectors.

In the pixel gray scale distribution discussed above, it was assumed that all pixels below a specific gray scale or threshold (TGS), represented specks and the pixels above the threshold represented peanut butter (see Fig. 2). The percent of total pixels below the TGS was assumed to be proportional to the total area of specks in the sample. Since the color or degree of roast will vary among samples, the TGS was computed as a function of the AGS.

$$TGS = C \bullet AGS \qquad (2)$$

where C is a constant. Once TGS is computed the percent of total pixels below TGS can be computed from the pixel gray scale distribution and is defined as the speck index (SI), or

$$SI = \sum_{i=0}^{TGS} n(i) / \sum_{i=0}^{255} n(i) \qquad (3)$$

The value of C was determined by trial and error techniques. The average gray scale was first computed for each of the 52 samples. Then for a given value of C, SI was computed for each of the 52 samples and then compared to the consensus AMS defect classification for each sample. The above process was repeated for various values of C until a value was obtained that gave the fewest number of mismatches and mismatches that were only in the two transition zones AB and BS.

Variability Studies - After C was determined, the total variability associated with testing replicated samples from the same lot with the video system was estimated for both SI and AGS. The total variance associated with either measurement was assumed to be the sum of sampling variance and instrument variance. For speck measurement, sampling variance is defined as the variance among SI values for replicated samples with a 33.6 cm^2 measurement area (5.8 cm by 5.8 cm) taken from the same lot of peanut butter. Instrument variance is defined as the variance among SI values of replicated measurements on the same sample with a 33.6 cm^2 measurement area. Total, sampling, and instrument variances are defined in a similar manner for AGS.

Seventeen estimates of total variance were determined by measuring both SI and AGS for 20 samples from each of 17 different peanut butter lots. Seven estimates of instrument variance were determined by measuring both SI and AGS 20 times on each of seven samples from different lots. Sampling variance was estimated by subtracting instrument variance from total variance for both SI and AGS.

Results

The AMS defect (speck) grade, the AMS color category, AGS, and SI for five different values of C are shown for each of the 52 samples in Table 1. The samples are listed in the table by identification numbers (ID) which were assigned as the samples were received from the field.

Table 1. The AMS speck and color grades, the measured color index, and the measured speck index for five values of C for 52 peanut butter samples.

Sample ID	AMS Defect Grade	AMS Color Category	AGS	Speck Index Values Of C 0.70	0.73	0.75	0.78	0.80
1	B	3.5	115.6	.075	.110	.154	.253	.349
2	AB	3.0	127.5	.065	.089	.112	.149	.179
3	A	3.5	112.7	.023	.035	.044	.072	.097
4	A	3.5	113.8	.010	.018	.022	.043	.068
5	AB	3.5	113.0	.051	.071	.085	.118	.152
6	A	3.5	112.8	.013	.023	.027	.049	.073
7	BS	3.0	124.8	.147	.193	.232	.310	.393
8	S	3.0	126.5	.154	.221	.269	.358	.447
9	B	3.0	125.9	.114	.172	.216	.303	.375
10	B	3.0	127.2	.090	.125	.155	.206	.255
11	B	3.0	127.6	.076	.100	.121	.173	.218
12	B	3.0	126.9	.051	.087	.114	.164	.227
13	B	3.5	106.4	.098	.134	.164	.269	.350
14	S	3.5	102.4	.209	.306	.385	.552	.717
15	A	3.5	117.5	.005	.010	.020	.037	.049
16	A	3.5	122.7	.013	.026	.033	.044	.064
17	A	3.0	135.3	.008	.011	.013	.019	.025
18	A	2.5	139.2	.008	.012	.016	.021	.026
19	A	2.5	144.1	.036	.048	.057	.077	.110
20	AB	3.5	118.6	.060	.090	.116	.172	.218
21	S	3.5	79.8	.728	1.123	1.398	2.042	2.807
22	S	4.5	37.3	2.586	3.579	4.293	6.015	7.507
23	A	3.0	128.4	.040	.055	.072	.108	.136
24	A	2.0	150.2	.008	.011	.015	.024	.034
25	AB	2.5	139.6	.054	.073	.100	.157	.201
26	A	3.5	118.6	.004	.008	.010	.021	.033
27	A	3.5	119.6	.011	.015	.019	.032	.038
28	A	3.5	117.4	.020	.024	.029	.038	.046
29	B	3.5	107.9	.066	.115	.151	.227	.325
30	B	3.5	107.8	.077	.117	.154	.273	.385
31	B	3.5	106.7	.106	.156	.199	.329	.447
32	A	3.5	119.0	.040	.053	.067	.096	.124
33	A	2.5	140.5	.013	.017	.021	.032	.039
34	A	3.5	115.6	.013	.022	.026	.045	.062
35	A	2.5	137.4	.025	.032	.039	.058	.077
36	A	2.0	149.7	.005	.005	.006	.009	.015
37	A	2.5	135.8	.003	.004	.007	.014	.021
38	A	3.5	126.7	.009	.016	.023	.036	.051
39	S	3.5	90.7	.475	.689	.838	1.201	1.672
40	S	3.5	91.8	.438	.652	.806	1.155	1.630
41	S	3.5	106.0	.248	.395	.503	.764	.982
42	S	3.5	106.9	.258	.411	.521	.825	1.085
43	A	3.0	129.6	.014	.019	.026	.046	.068
44	A	3.0	130.6	.013	.018	.020	.031	.046
45	B	3.5	112.9	.111	.155	.197	.317	.453
46	B	3.5	115.6	.140	.197	.251	.383	.532
47	A	3.5	124.8	.027	.038	.048	.068	.087
48	A	3.5	123.4	.018	.024	.035	.055	.075
49	A	3.5	125.4	.019	.027	.030	.040	.050
50	A	2.5	137.0	.025	.041	.052	.067	.090
51	B	3.5	105.5	.093	.140	.187	.293	.377
52	B	3.0	129.6	.054	.079	.100	.163	.228

[a]C - threshold gray scale/average gray scale

Speck Index - The SI values were computed using C values that varied from 0.7 to 0.8. For a given sample, as C increases SI increases because more of the 147,456 pixels represent specks. Table 2 is a listing of the 52 SI values ordered from low to high and the corresponding AMS defect grades for C values of 0.70, 0.73, 0.75, 0.78 and 0.80. A perfect match occurs with the SI values when the AMS defect grades are ordered A, AB, B, BS and S. No C value gave SI values that matched perfectly with the AMS defect grades. For C values of 0.73 and 0.75, two mismatches occurred in the transition zone AB and one mismatch occurred in transition zone BS where the samples were difficult for the AMS inspectors to classify. A C value of 0.75 was chosen as the preferred value for this study.

To utilize SI, two critical values (SIab and SIbs) need to be established that will separate samples into one of the three AMS defect grade categories, A, B, or S. Samples with SI values less than SIab would be given a grade of A; samples with SI values between SIab and SIbs would be given a grade of B; and samples with SI values greater than SIbs would be given a grade of S. The critical speck index SIab was calculated by averaging the largest SI value for grade A (0.072), the smallest SI value for grade B (0.100), and all SI values for the AB classification (0.085, 0.100, 0.112, and 0.116). The average of the above SI values was 0.0975. The critical speck index SIbs was calculated by averaging the largest SI value for grade B (0.251), the smallest SI value for grade S (0.269), and all SI value for the BS classification (0.232). The average of the above SI values was 0.250. These values of SIab and SIbs are only preliminary values and final critical values will be established after tests with a large number of samples in cooperation with AMS.

Table 2. Ordered speck index values and AMS speck grades for five C values for 52 peanut butter samples.

C - Threshold gray scale/average gray scale: 0.70 ID	Speck Index	AMS Grade	0.73 ID	Speck Index	AMS Grade	0.75 ID	Speck Index	AMS Grade	0.78 ID	Speck Index	AMS Grade	0.80 ID	Speck Index	AMS Grade
37	.003	A	37	.004	A	36	.006	A	36	.009	A	36	.015	A
26	.004	A	36	.005	A	37	.007	A	37	.014	A	37	.021	A
15	.005	A	26	.008	A	26	.010	A	17	.019	A	17	.025	A
36	.005	A	15	.010	A	17	.013	A	18	.021	A	18	.026	A
17	.008	A	17	.011	A	24	.015	A	26	.021	A	26	.033	A
18	.008	A	24	.011	A	18	.016	A	24	.024	A	24	.034	A
24	.008	A	18	.012	A	27	.019	A	44	.031	A	27	.038	A
38	.009	A	27	.015	A	15	.020	A	27	.032	A	33	.039	A
4	.010	A	38	.016	A	44	.020	A	33	.032	A	28	.046	A
27	.011	A	33	.017	A	33	.021	A	38	.036	A	44	.046	A
6	.013	A	4	.018	A	4	.022	A	15	.037	A	15	.049	A
16	.013	A	44	.018	A	38	.023	A	28	.038	A	49	.050	A
33	.013	A	43	.019	A	34	.026	A	49	.040	A	38	.051	A
34	.013	A	34	.022	A	43	.026	A	4	.043	A	34	.062	A
44	.013	A	6	.023	A	6	.027	A	16	.044	A	16	.064	A
43	.014	A	28	.024	A	28	.029	A	34	.045	A	4	.068	A
48	.018	A	48	.024	A	49	.030	A	43	.046	A	43	.068	A
49	.019	A	16	.026	A	16	.033	A	6	.049	A	6	.073	A
28	.020	A	49	.027	A	48	.035	A	48	.055	A	48	.075	A
3	.023	A	35	.032	A	35	.039	A	35	.058	A	35	.077	A
35	.025	A	3	.035	A	3	.044	A	50	.067	A	47	.087	A
50	.025	A	47	.038	A	47	.048	A	47	.068	A	50	.090	A
47	.027	A	50	.041	A	50	.052	A	3	.072	A	3	.097	A
19	.036	A	19	.048	A	19	.057	A	19	.077	A	19	.110	A
23	.040	A	32	.053	A	32	.067	A	32	.096	A	32	.124	A
32	.040	A	23	.055	A	23	.072	A	23	.108	A	23	.136	A
5	.051	AB	5	.071	AB	5	.085	AB	5	.118	AB	5	.152	AB
12	.051	B	25	.073	AB	25	.100	AB	2	.149	AB	2	.179	AB
25	.054	AB	52	.079	B	52	.100	B	25	.157	AB	25	.201	AB
52	.054	B	12	.087	B	2	.112	AB	52	.163	B	20	.218	AB
20	.060	AB	2	.089	AB	12	.114	B	12	.164	B	11	.218	B
2	.065	AB	20	.090	AB	20	.116	AB	20	.172	AB	12	.227	B
29	.066	B	11	.100	B	11	.121	B	11	.173	B	52	.228	B
1	.075	B	1	.110	B	29	.151	B	10	.206	B	10	.255	B
11	.076	B	29	.115	B	1	.154	B	29	.227	B	29	.325	B
30	.077	B	30	.117	B	30	.154	B	1	.253	B	1	.349	B
10	.090	B	10	.125	B	10	.155	B	13	.269	B	13	.350	B
51	.093	B	13	.134	B	13	.164	B	30	.273	B	9	.375	B
13	.098	B	51	.140	B	51	.187	B	51	.293	B	51	.377	B
31	.106	B	45	.155	B	45	.197	B	9	.303	B	30	.385	B
45	.111	B	31	.156	B	31	.199	B	7	.310	BS	7	.393	BS
9	.114	B	9	.172	B	9	.216	B	45	.317	B	31	.447	B
46	.140	B	7	.193	BS	7	.232	BS	31	.329	B	8	.447	S
7	.147	BS	46	.197	B	46	.251	B	8	.358	S	45	.453	B
8	.154	S	8	.221	S	8	.269	S	46	.383	B	46	.532	B
14	.209	S	14	.306	S	14	.385	S	14	.552	S	14	.717	S
41	.248	S	41	.395	S	41	.503	S	41	.764	S	41	.982	S
42	.258	S	42	.411	S	42	.521	S	42	.825	S	42	1.085	S
40	.438	S	40	.652	S	40	.806	S	40	1.155	S	40	1.630	S
39	.475	S	39	.689	S	39	.838	S	39	1.201	S	39	1.672	S
21	.728	S	21	1.123	S	21	1.398	S	21	2.042	S	21	2.807	S
22	2.586	S	22	3.579	S	22	4.293	S	22	6.015	S	22	7.507	S

Color Index - The 52 measured AGS values in Table 1 were ordered from low to high and are shown in Table 3 along with the AMS color category for each sample. A low AGS value indicates a dark brown color while a high AGS indicates a light brown color. The data indicate that there is a good agreement between AGS and the AMS color category. The 52 AMS color categories match the order of the AGS values except for the AGS values of 124.8 and 126.7.

Critical color index values could not be established with these 52 samples since 51 samples had a color that was graded A (color category between 1 and 4) by the AMS inspectors. Further tests will have to be made with samples which have colors that span all three color grades.

Variance Estimates - The total variance SVT and instrument variance SVI associated with SI is shown in Figs. 3 and 4, respectively. Both variance components

Table 3. Ordered color index values and AMS color grades for 52 peanut butter samples.

ID	AGS	AMS Color Categories	ID	AGS	AMS Color Categories
22	37.3	4.5	16	122.7	3.5
21	79.8	3.5	48	123.4	3.5
39	90.7	3.5	47	124.8	3.5
40	91.8	3.5	7	124.8	3.0
14	102.4	3.5	49	125.4	3.5
51	105.5	3.5	9	125.9	3.0
41	106.0	3.5	8	126.5	3.0
13	106.4	3.5	38	126.7	3.5
31	106.7	3.5	12	126.9	3.0
42	106.9	3.5	10	127.2	3.0
30	107.8	3.5	2	127.5	3.0
29	107.9	3.5	11	127.6	3.0
3	112.7	3.5	23	128.4	3.0
6	112.8	3.5	43	129.6	3.0
45	112.9	3.5	52	129.6	3.0
5	113.0	3.5	44	130.6	3.0
4	113.8	3.5	17	135.3	3.0
34	115.6	3.5	37	135.8	2.5
1	115.6	3.5	50	137.0	2.5
46	115.6	3.5	35	137.4	2.5
28	117.4	3.5	18	139.2	2.5
15	117.5	3.5	25	139.6	2.5
26	118.6	3.5	33	140.5	2.5
20	118.6	3.5	19	144.1	2.5
32	119.0	3.5	36	149.7	2.0
27	119.6	3.5	24	150.2	2.0

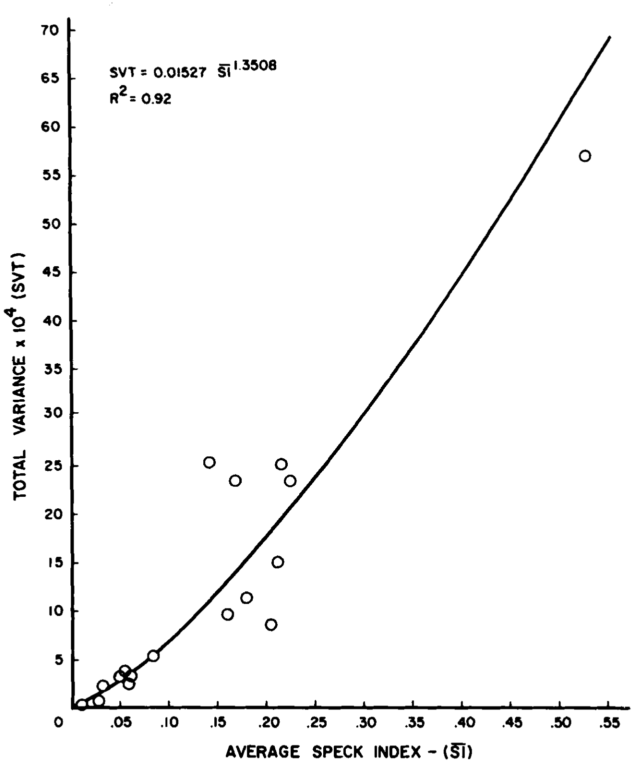

Fig. 3. Relationship between the total variance for speck index SVT and the average speck index SI when measuring a 33.6 cm^2 area of peanut butter. Coefficient of determination R^2 = 0.92.

appear to be a function of the magnitude of the SI. As the average speck index $\overline{SI}$ increases, both SVT and SVI increase. A power function of the general form

$$SVT = a\ SI^b \quad (4)$$

was used to describe the empirical relationship between SVT and $\overline{SI}$ where a and b are constants independent of $\overline{SI}$. Using the Statistical Analysis System (SAS), the constants a and b were determined by a least squares fit of the logarithmic value of variance to the logarithmic value of SI which gives equal weight to the residuals from the line in the logarithmic scale, thus minimizing the effect of a large deviation in the variance scale. The

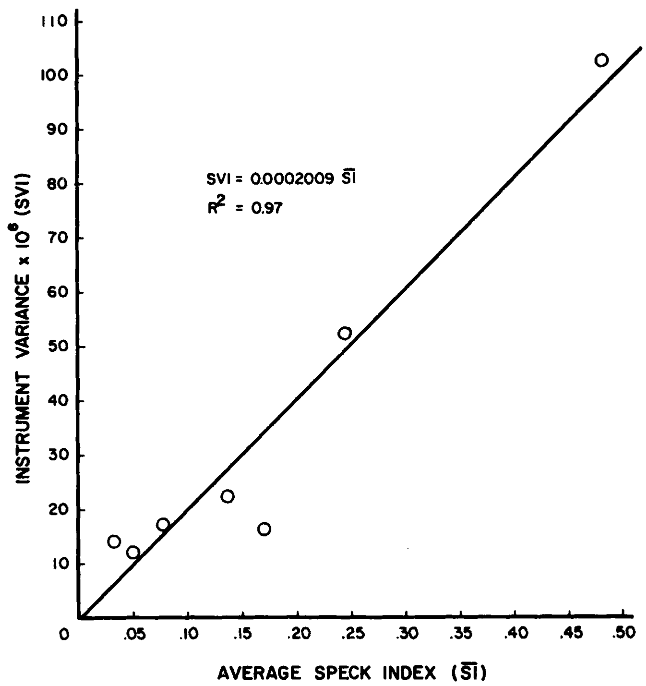

Fig. 4. Relationship between the instrument variance for speck index SVI and the average speck index SI when making one measurement on a 33.6 cm^2 area of peanut butter. Coefficient of determination R^2 = 0.97.

regression analysis gave the following expression

$$SVT = 0.01527\ \overline{SI}^{1.3508}, \quad (5)$$

with a coefficient of determination of 0.92. A linear function gave the best fit between SVI and $\overline{SI}$. When the linear equation is used

$$SVI = 0.000201\ \overline{SI} \quad (6)$$

with a coefficient of determination of 0.97. The SI sampling variance SVS can be determined by subtracting Eq. 5 from Eq. 6.

$$SVS = 0.01527\ \overline{SI}^{1.3508} - 0.000201\ \overline{SI}. \quad (7)$$

The instrument, sampling, and total coefficients of variation for a SI of 0.1 was computed with the above equations to be 4.6, 25.7, and 26.1 percent, respectively.

The total variance AVT and instrument variance AVI associated with AGS is shown in Figs. 5 and 6, respectively. The AVI appears to be a function of the average AGS values $\overline{AGS}$ while AVT does not appear to be a function of $\overline{AGS}$. The power function in Eq. 4 was used to describe the relationship between AVI and $\overline{AGS}$. The regression analysis gave the fcllowing expression for the instrument variance.

$$AVI = 5.2 \times 10^{-14}\ \overline{AGS}^{5.9311}. \quad (8)$$

The coefficient of determination was 0.85.

AVT appears to be a constant because the slope in the regression analysis was not significantly different from zero at the 5% confidence level. Therefore AVT was determined by averaging the 17 variance estimates.

$$AVT = 1.054. \quad (9)$$

The sampling variance AVS can be estimated by subtracting Eq. 8 from Eq. 9,

$$AVS = 1.054 - 5.2 \times 10^{-14}\ \overline{AGS}^{5.9311} \quad (10)$$

The instrument, sampling, and total coefficients of variation for AGS of 120 was computed with the above equations to be 0.28, 0.81, and 0.85 percent, respectively.

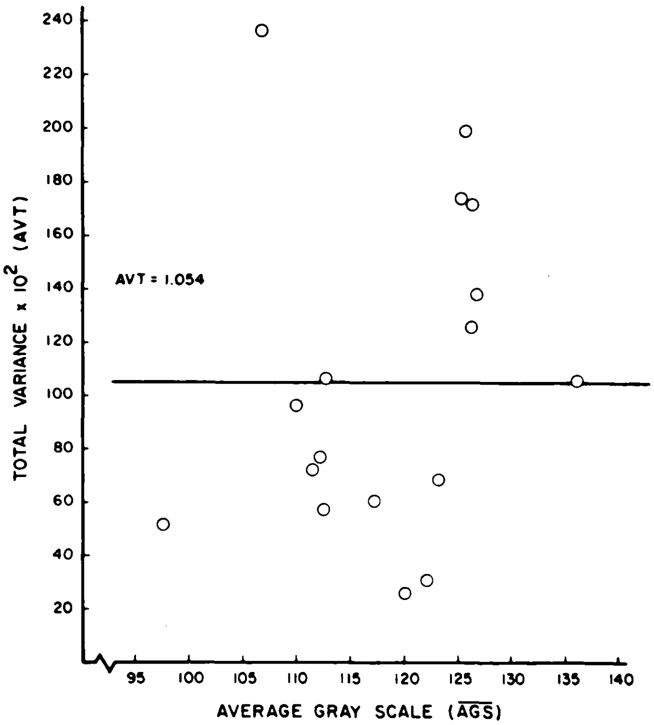

Fig. 5. Relationship between the total variance for color index AVT and the average color index AGS when measuring 33.6 cm^2 area of peanut butter.

The errors associated with the AGS are much lower than the errors associated with SI.

The sampling variance expressions in Eqs. 7 and 10 associated with SI and AGS are unique for the 33.6 cm^2 surface area measured. The sampling variance for both SI and AGS can be reduced by increasing the surface area measured. The sampling variance for measuring SI and AGS for a given area AR in cm^2 becomes

$$SVS = (33.6/AR)[0.01527\ \overline{SI}^{1.3508} - 0.000201\ \overline{SI}] \quad (11)$$

$$AVS = (33.6/AR)[1.054 - 5.2 \times 10^{-14}\ \overline{AGS}^{5.9311}], \quad (12)$$

respectively. If AR is equal to 33.6 then Eqs. 11 and 12 are equal to Eqs. 9 and 10. From Eqs. 11 and 12 it can be seen that doubling the area (AR = 67.2) cuts the variance in half and the coefficient of variation by the square root of 2.

The instrument variance expressions in Eqs. 5 and 8 associated with SI and AGS are unique for a single measurement. The instrument variance for both SI and AGS can be reduced by increasing the number of measurements N. The instrument variance for SI and AGS for a given number of measurements becomes

$$SVI = (1/N)(0.000201\ \overline{SI}),$$

$$AVI = (1/N)[5.2 \times 10^{-14}\ \overline{AGS}^{5.9311}],$$

respectively. If N is equal to one then Eqs. 13 and 14 are equal to Eqs. 5 and 8. From Eqs. 13 and 14 it can be seen that doubling the number of measurements (N = 2) cuts the instrument variance in half and the coefficient of variation by the square root of 2.

Conclusions

Computed SI and AGS values agreed with the observed AMS defect and color categories, respectively. AGS, while not actually measuring color or hue, had a good correlation with the AMS color categories since all peanut butter samples have similar shades of brown. The instrument error was less than five percent for specks and less than one percent for color determinations. When using a sample area of 33.6 cm^2, the sampling error associated with measuring specks was 25.7% compared to 0.81% for measuring color. These studies demonstrated that video image analysis techniques can be used successfully to determine the AMS defect and color grades for peanut butter samples.

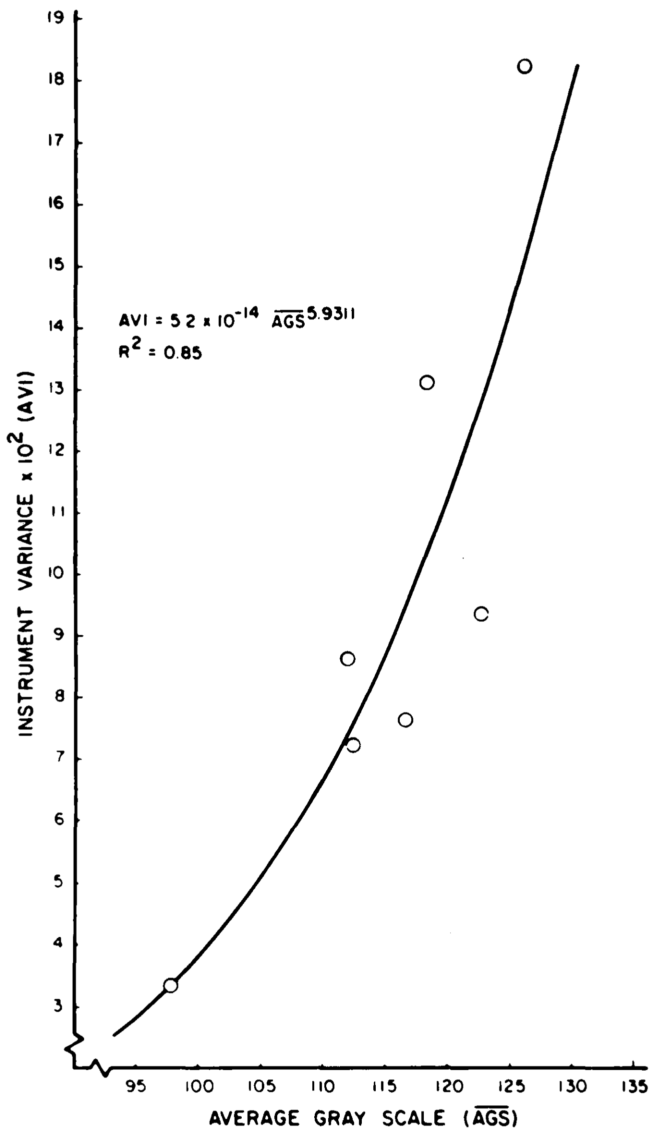

Fig. 6. Relationship between the instrument variance for color index AVI and the average gray scale AGS when making one measurement on a 33.6 cm^2 area of peanut butter. Coefficient of determination R^2 = 0.85.

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