Identifying Undamaged and Damaged Peanut Kernels Using Tristimulus Values and Spectral Reflectance

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Abstract

Peanut kernels from grade samples were sorted into damaged and undamaged categories based measurements from four optical sensing methods. A monochromatic machine vision system, a contact colorimeter, a non-contact colorimeter and a spectrophotometer correctly classified 62.7%, 79.1%, 85.8%, and 94.1%, respectively, of the damaged kernels while correctly classifying 100% of the undamaged kernels. Further analysis of the spectrophotometer data resulted in 99% correct classification of damaged kernels when critical spectral reflectance ranges and line slopes at specific wavelengths were used.
Keywords. Inspection, Grading, Peanuts, Spectral reflectance, Machine vision, Color, Colorimeter.

Introduction

Quality evaluations are made on samples of all peanuts (*Arachis hypogaea*, L.) marketed in the United States. These evaluations include measuring the moisture content, damaged kernels, and kernels of different size categories. Kernel size and moisture content are measured using machines. However, damaged kernels are evaluated subjectively using trained inspectors.

Kernel damage may occur any time in the production, marketing, storage, or manufacturing process. Damage may be caused by insects, fungal growth, improper curing, or freeze damage. Most types of damage will usually result in poor flavor or in toxic residues produced by fungal growth. Inspectors are trained to identify kernel discolorations (USDA, 1988) but are subject to error. Because of the variability due to the tedious nature of the job and the burden placed on individual inspectors, the peanut industry has requested that an objective means of determining damage be developed.

Peanuts are inspected once when the farmer markets his crop, and again when the peanuts are marketed as shelled kernels. The percentage and type of damage detected indicate the quality of the peanuts and is reflected in the price of the peanuts. The presence and quantity of certain types of damage can result in penalties to growers of 1 to 75% of the value of the peanuts. Sheller losses occur when remilling is required to remove damaged kernels when damage percentage is above 1%. From a quality standpoint, the correct identification of certain types of fungal damage is critical since fungal damage is an indication of the presence of aflatoxin, a carcinogen, in peanuts. Accurate identification of kernel damage is essential to insure objective peanut quality assessment.

The objective of this research was to determine the effectiveness of using quantitative optical measurements to classify damaged and undamaged peanut kernels. Specifically, classification criteria will be developed and accuracy of several means of quantitating spectral properties of kernels determined.

Literature Review

The human eye can distinguish several million colors; however, our ability to use the same criteria to repeatedly determine the color of an object is poor. In addition, two observers may differ in their opinion of what is, for example, dark brownish-grey. Human bias can be removed from the color measurement process through the use of instruments which measure color such as spectrophotometers or colorimeters.

Spectrophotometers provide an objective measurement of the color of a surface in terms of reflectance at specific wavelengths. Reflectance is the ratio of reflected to incident light and is determined for as many wavelengths as desired (MacAdams, 1985).

Colorimeters simulate the color response of the human eye. Colorimeters use filters and sensors to measure the three primary colors, thus enabling determination of tristimulus values. The tristimulus values can be translated into three-dimensional sets of color space coordinates which indicate color as perceived by the human eye. The three dimensions describe hue, saturation, and intensity or lightness of an object. Hue indicates what color, such as red, dominates the reflected light. Saturation indicates how much of the color is there, such as vivid red. Intensity indicates how bright the color is, such as light red (Minolta, 1988).

Color machine vision systems have been used to determine the color of agricultural commodities. Wigger et al. (1988) classified fungal-damaged soybeans with about 98% accuracy using a color machine vision system. Intensity and ratios of red to blue, red to green, and green to blue were used to classify kernels instead of hue, saturation, and intensity values. Shyy and Misra (1989) used similar procedures to classify damaged soybeans with about 85% accuracy. Miller and Delwiche (1988) graded

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Article has been reviewed and approved for publication by the Food and Process Engineering Inst. of ASAE. Presented as ASAE Paper No. 90-6594.

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peaches by color using red, green, and blue inputs. They used diffuse lighting and normalized luminance to reduce the red, green, and blue inputs to two-dimensional chromaticity coordinates. Peaches were correctly classified with 65% accuracy and with a correlation coefficient of 0.90.

Color filters on black and white cameras allow color information to be obtained without the expense of a color system. Gunasekaran et al. (1988) used a red filter (610 nm) on a black and white machine vision system to classify fungal-damaged soybeans and corn kernels. Corn kernels were classified correctly 84% of the time and soybeans 80% of the time.

PROCEDURES

Three methods for objective classification of damaged and undamaged peanut kernels were tested: 1) intensity measurement only; 2) hue, saturation, and intensity measurements; and 3) measurement of the relative reflectance over the visible spectrum.

DAMAGE DETECTION BY INTENSITY MEASUREMENT

Intensity, measured by grey levels, was measured using a black and white machine vision system. A Dage Newvicon MTI-65 tube camera viewed objects that were analyzed by an Imaging Technologies, Inc. Model 151 imaging system. The camera lens was placed 11.4 cm above the viewing area. The system had 512×512 pixel resolution with individual pixel resolution of 0.025 mm, digitized 256 grey levels, and had an aspect ratio of 4:5. The system was controlled and data were collected using a Compaq Model 40 portable 20 mHz computer with an 80386 processor. A Moritex mhf 150 L fiber optic ring light attached to the camera lens provided illumination. A 120 PVC black friction belt was used as a background when viewing freeze damaged kernels whereas a Dorner #1 hard top accumulator white belt was used as a background for viewing other damaged kernels.

A grey scale threshold was determined by observing damaged and undamaged kernels with the machine vision system and then choosing a threshold that gave minimum misclassification errors. This resulted in a grey scale threshold of 15 and 103 for redskin and blanched kernels, respectively. The percentage of discoloration in the projected area of the darkest side of each kernel was recorded. If 50% of the side of the kernel being viewed was discolored, then the kernel was classified as damaged. Individual kernels were hand placed into the viewing area.

DAMAGE DETECTION BY HUE, SATURATION, AND INTENSITY MEASUREMENT

A Minolta Chroma Meter CR-200 and a Minolta Chroma Meter CS100 were used to determine the hue, saturation, and intensity of damaged and undamaged peanut kernels. The CR-200 had an 8-mm diameter measuring area and a built-in pulsed xenon arc lamp. L*a*b*, L*C*H°, and Yxy color space coordinates were stored on a computer disk for later analysis. The CIE standard illuminant C was used to calibrate the meter.

Kernels were individually placed on a glass specimen plate directly over the viewing area. The specimen plate insured that all kernels were the same distance from the viewing area. Initial tests showed that viewing through the plate did not adversely affect meter readings. The 8-mm diameter viewing area gathered light reflected from about one-half of the projected kernel area.

The CS-100 was tested since it did not have to be in contact with the kernel. A lens was used to achieve a 10-mm diameter viewing area. As with the CR-200 meter, only about one-half of the projected kernel area was viewed. The meter was attached to a stand with the meter lens positioned about 15 cm from the kernel. An 80 cm by 130 cm Graphic Technology, Inc. viewing station with a D7500 light source provided uniform consistent illumination. CIE standard illuminant D65 was used to calibrate the meter. All ambient lighting was excluded during testing by turning off all room lights and covering all room openings.

The minimum and maximum color space coordinate values for undamaged redskin and blanched kernels were determined in preliminary testing for the CR-200 and CS-100. All damaged kernels were then compared to those established thresholds. Neither colorimeter can determine the amount of surface area discolored, thus, only the color, not amount of kernel discolored, was determined.

DAMAGE DETECTION BY SPECTRAL REFLECTANCE

An X-Rite 968 reflection spectrophotometer was used to measure kernel spectral reflectance from 400 nm to 700 nm in 10 nm intervals. The spectrophotometer had a 0° illumination angle, 45° viewing angle, and an 8-mm diameter target window. The target window was placed over the darkest discoloration on the kernels. Kernels were individually placed by hand into the viewing area. All data was collected and stored on a computer. The CIE illuminant C was used to calibrate the meter.

As with both chroma meters, the percentage of surface discolored could not be determined. Thus, only spectral information was collected. Spectral curve thresholds were selected that resulted in minimum misclassification of the total number of damaged and undamaged kernels tested.

DESCRIPTION OF TESTS

Three separate tests (Table 1) were conducted to evaluate the effectiveness of each sensor when separating damaged from undamaged runner-type peanut kernels. Initial classification of all samples was done by the Federal State Inspection Service (FSIS). Test 1 compared the effectiveness of the four sensors when classifying obviously damaged, questionably damaged, questionably undamaged, obviously undamaged, and freeze damaged blanched and redskin peanut kernels obtained from crop year (CY) 1989. Approximately 100 kernels of each category were used in this initial test. Minimum and maximum thresholds for the machine vision system and chroma meters were selected such that 100% of all undamaged kernels were correctly classified. For the spectrophotometer, shape features were identified by measuring the minimum and maximum spectral reflectance ranges and slopes of 200 undamaged kernels at locations where sharp changes in the shape of the curve were observed. If the spectral curve describing a kernel fell outside of the undamaged kernel minimum and maximum values, the kernel was considered damaged. Test 2 determined the optimum wavelengths that can be used to

TABLE 1. Number of peanut kernels used to test the effectiveness of a black and white machine vision system, two colorimeters, and a spectrophotometer when classifying damaged and undamaged peanut kernels

Category	Test 1*	Test 2*	Test 3*
Undamaged blanched	100	100	500
Undamaged redskin	100	100	500
Questionably undamaged	100		
Questionably damaged	100		
Damaged†	100	500	500
Freeze damaged	73		
Total kernels	573	700	1500

* A black and white machine vision system, two colorimeters and a spectrophotometer were compared in Test 1. Tests 2 and 3 classified kernels using only a spectrophotometer.

† The damaged kernel category in Tests 2 and 3 includes damaged, questionably undamaged, questionably damaged, and freeze damaged kernels.

TABLE 2. Percentage of undamaged or damaged kernels classified as undamaged kernels when using a CR-200 or CS-100 chroma meter, a black and white machine vision system, or a spectrophotometer*

Damage Category	Machine Vision (%)	CR-200 (%)	CS-100 (%)	Spectro-photometer (%)
Undamaged redskins	100 A	100 A	100 A	100 A
Undamaged blanched	100 A	100 A	100 A	100 A
Questionably undamaged	68 C	32 B	21 AB	7 A
Questionably damaged	31 B	21 AB	12 A	12 A
Damaged	40 C	19 B	16 B	3 A
Freeze damaged (blanched)	0 A	6 B	4 B	0 A
Undamaged kernels classified correctly	100 A	100 A	100 A	100 A
Damaged kernels incorrectly classified	37 A	21 B	14 B	6 C

* Means in rows followed by the same letter are not significantly different at P = 0.05. There were 100 kernels in each category except for freeze damaged which contained 73 kernels.

classify damaged and undamaged kernels by calculating the minimum and maximum spectral reflectance ranges of undamaged blanched and redskin kernels at 10 nm increments along with the minimum and maximum undamaged kernel line slopes from 400 to 700 nm over distances of 10 nm to 300 nm. The number of kernels that were correctly classified using each of these ranges or line slopes determined to optimum wavelengths that were selected. The categories of obviously damaged, questionably damaged, questionably undamaged, and freeze damaged were all grouped into one category of

TABLE 3. Damaged and undamaged peanut kernel color space coordinate values obtained from a Minolta CR-200 colorimeter and the amount of surface area discolored as determined by machine vision*

Damage Category	L*	a*	b*	C*	H	Y	x	y	Percent Discolor
Undamaged redskins									
Mean	56.0 a	9.0 a	19.1 a	21.1 a	66.9 a	24.0 ab	0.384 a	0.360 a	0.16 a
S.D.	2.4	1.1	1.5	1.3	4.6	2.5	0.0042	0.0044	0.19
Undamaged (blanched)									
Mean	73.9 b	−2.8 b	18.4 bb	18.6 b	99.5 b	46.7 c	0.347 e	0.362 a	0.0 a
S.D.	1.9	0.5	1.3	1.4	1.1	2.9	0.0028	0.0034	0.0
Questionably damaged									
Mean	51.8 cf	6.0 c	15.7 b	17.0 c	71.9 c	20.8 d	0.372 b	0.357 b	12.2 b
S.D.	8.1	2.6	3.7	3.2	13.6	8.5	0.010	0.0098	8.4
Questionably damaged									
Mean	56.2 a	4.7 d	16.8 c	17.6 c	80.3 d	25.6 a	0.369 bc	0.361 a	21.7 c
S.D.	10.5	3.0	4.2	3.7	15.1	11.3	0.0087	0.011	13.4
Damaged									
Mean	53.0 df	4.0 e	16.2 bc	16.9 c	81.5 d	22.1 bd	0.367 d	0.361 a	26.8 d
S.D.	8.6	3.3	4.6	4.6	11.4	8.6	0.013	0.012	22.1
Freeze damaged									
Mean	62.2 e	0.4 f	20.7 d	20.8 a	94.8 e	40.0 e	0.368 cd	0.374 c	100.0 e
S.D.	4.9	2.4	3.4	3.4	6.5	5.6	0.012	0.0090	0.0

* Means in columns followed by the same letter are not significantly different at P = 0.05.

damaged peanut kernels. Test 3 was similar to Test 2 except the Test 2 wavelengths were further optimized by noting that most maximum slopes and reflectance values and one minimum value contributed little to the kernel classifications or adversely affected the undamaged kernel classifications. Thus, 1500 kernels from CY 1990 were classified with only maximum or minimum values. The kernels were oriented in the viewing are such that the portion of each kernel showing the most discoloration was analyzed in all tests.

Sensor performance can be evaluated by calculating the percentage of good kernels classified as damaged kernels or by calculating the percentage of damaged kernels classified as good kernels. If damaged kernels are erroneously classified as good kernels, then poor quality peanuts may reach the consumer. Thus, correctly classifying damaged kernels was considered more significant in evaluating the sensors since guaranteeing quality peanuts is the primary goal of the U.S. peanut industry.

For the reasons cited above, the categories of questionably undamaged and questionably damaged peanuts were treated as damaged peanuts since there was some doubt as to their quality by the inspectors. Thus, the sensors were evaluated to determine how accurately and consistently obviously undamaged redskin and blanched kernels could be separated from all other categories.

Results and Discussion

Machine Vision Results

The machine vision system classified 100% of the freeze damaged kernels correctly. However, misclassifications of 31% to 68% of the questionably damaged, questionably undamaged, and damaged categories occurred when using the optimum threshold value (Table 2). Damaged kernels are those that had more than 25% of the kernel surface discolored A significant increase in the percent discoloration was seen as the degree of damage increased (Table 3), however, 37.3% of all damaged kernels were incorrectly classified as undamaged.

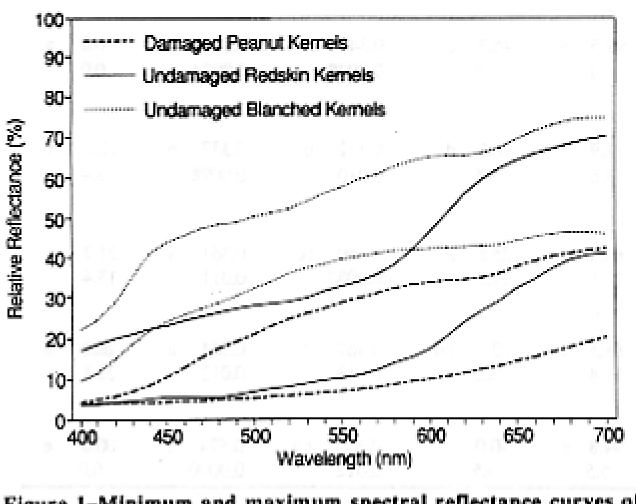

Figure 1–Minimum and maximum spectral reflectance curves of undamaged redskin and undamaged blanched kernels and typical curves for damaged kernels.

TABLE 4. Minimum and maximum relative spectral reflectance at specified points used to characterize undamaged redskin and undamaged blanched kernels

Wavelength (nm)	Min (%)	Max (%)
Redskins		
400	3.56	16.93
550	9.87	32.53
580	13.45	37.90
630	26.54	59.38
700	40.73	70.00
Blanched		
400	9.60	22.10
440	21.67	40.94
590	41.95	64.17
640	43.13	67.17
670	45.81	72.64
700	45.74	74.37

Chroma Meter Results

The CS-100 and CR-200 results were statistically similar to each other. This similarity was expected since the meters are of similar technology, the only differences being the illumination and viewing methods. The three color spaces, L*a*b*, L*C*H°, and Yxy showed similar significant differences between categories which can be expected since the three color spaces are mathematical transformations of each other (Table 3). Significant differences between some damage categories were seen for all color space coordinates; however, the standard deviations show that much overlap between categories occurred as shown in Table 2 where undamaged and damaged kernels were classified based on their L*a*b* values.

Misclassification of damaged kernels by the CR-200 ranged from 6% for freeze damage to 32% for the questionably undamaged kernels (Table 2). An average of 20.9% of all damaged kernels were misclassified. Slightly less damaged kernels were misclassified with the CS-100 with 14.2% of all damaged kernels misclassified; however, differences between the CS-100 and CR-200 were not significant.

TABLE 5. Minimum and maximum slopes of relative spectral reflectance used to characterize undamaged redskin and undamaged blanched kernels

Wavelength Range (nm)	Min Slope (% / nm)	Max Slope (% / nm)
Redskins		
400 - 550	0.04	0.11
550 - 580	0.11	0.21
580 - 630	0.22	0.49
630 - 700	0.09	0.28
Blanched		
400 - 440	0.28	0.54
440 - 590	0.10	0.20
590 - 640	−0.01	0.07
640 - 670	0.09	0.23
670 - 700	−0.01	0.08

The measure of luminance, L* or Y, with the CR-200 and CS-100 showed much overlap between damage categories. This indicates that although the hue and saturation of damaged kernels may be different, the intensity of the colors is similar. This is supported by the poor performance of the machine vision results where only intensity was measured. Significant decreases in most a*, C*, and x values were seen as the degree of damage increased. A slight increase in b*, H°, and y values from obviously undamaged to obviously damaged kernels was seen. Although statistical differences between some categories was seen, substantial overlap between these classifications existed. Table 3 shows the means and standard deviations for all color space coordinates when using the CR-200.

TABLE 6. Optimum wavelength ranges or slopes based on 500 damaged and 200 undamaged kernels and the resulting classifications for redskin and blanched peanuts using eight different groups of wavelengths or slope selections

Wavelength Group		Wavelengths (nm)	Relative Reflectance (% or Slope) (% reflectance* / wavelength (nm)) Minimum	Maximum	Damaged Kernels Correctly Classified† (%)	Undamaged Kernels Correctly Classified† (%)
1	Blanched	430	8.29%	35.12%		
	Redskin	690	40.44%	69.21%	83.6 A†	100 A
2	Blanched	450	23.78%	43.83%		
	Redskin	520 - 670	0.1867% / nm	0.2666% / nm	96.6 B	100 A
3	Blanched	410 - 440	0.3250% / nm	0.6017% / nm		
	Redskin	520 - 670	0.1867% / nm	0.2666% / nm		
		440	5.05%	21.92%	96.6 B	100 A
4	Blanched	410 - 440	0.3250% / nm	0.6017% / nm		
		590 - 620	0.04825% / nm	0.1176% / nm		
	Redskin	520 - 670	0.1867% / nm	0.2666% / nm		
		440	5.05%	21.92%	97.0 B	100 A
5	Blanched	450	23.78%	43.83%		
	Redskin	520 - 670	0.1867% / nm	0.2666% / nm		
		450 - 580	0.0629% / nm	0.1307% / nm	97.4 B	100 A
6	Blanched	450	23.78%	43.83%		
		520	35.78%	52.12%		
	Redskin	570	11.84%	35.48%		
		450 - 580	0.06269% / nm	0.1307% / nm		
		520 - 670	0.1867% / nm	0.2666% / nm	97.6 B	100 A
7	Blanched	520	35.78%	52.12%		
		660 - 670	0.0680% / nm	0.1950% / nm		
		450	23.78%	43.83%		
	Redskin	520 - 670	0.1867% / nm	0.2666% / nm		
		450 - 580	0.06269% / nm	0.1307% / nm		
		660 - 700	0.01100% / nm	0.2680% / nm		
		660	34.43%	65.79%	98.2 B	100 A
8	Blanched	450	23.78%	43.83%		
		520	35.78%	52.12%		
		410 - 440	0.3250% / nm	0.6017% / nm		
		450 - 500	0.07920% / nm	0.2244% / nm		
		590 - 620	0.003333% / nm	0.05767% / nm		
	Redskin	560	10.46%	33.86%		
		570	11.84%	35.48%		
		660	34.43%	65.79%		
		680	39.08%	68.25%		
		520 - 670	0.1867% / nm	0.2666% / nm		
		450 - 580	0.06269% / nm	0.1307% / nm		
		550 - 570	0.09550% / nm	0.1820% / nm		
		600 - 610	0.2420% / nm	0.5930% / nm		
		660 - 700	0.01100% / nm	0.2680% / nm	99.0 B	100 A

* Kernels were classified as damaged if the relative reflectance or slope was less than the minimum or greater than the maximum value.

† Percentages in columns followed by the same letter are not significantly different at P = 0.05.

Spectrophotometer Results

The spectral curves for undamaged redskin and undamaged blanched kernels were plotted and features describing the spectral curve shape identified. Figure 1 shows typical damaged and undamaged redskin and blanched kernel curves. Tables 4 and 5 show the ranges and slopes used to characterize the slope of these curves. With these limits set, damaged kernels in each category were compared to the undamaged kernel parameters. With limits set as described, only 5.9% of the damaged kernels were misclassified and no undamaged kernels were misclassified (Table 1).

In addition to the above method of comparison, the Kolmogorov-Smirnov statistical test was used to compare

TABLE 7. Optimum wavelength ranges or slopes based on 500 damaged and 1000 undamaged kernels and the resulting classification for redskin and blanched peanuts using eight different groups of wavelength or slope selections

Wavelength Group		Wavelengths (nm)	Relative Reflectance (% or Slope) (% reflectance* / wavelength (nm))	Damaged Kernels Correctly Classified† (%)	Undamaged Kernels Correctly Classified† (%)
1	Blanched	430	< 8.29%		
	Redskin	690	< 40.44%	80.8 A	99.4 A
2	Blanched	450	< 23.78%		
	Redskin	520 - 670	< 0.1867% / nm	92.8 B	99.1 A
3	Blanched	410 - 440	< 0.3250% / nm		
	Redskin	520 - 670	< 0.1867% / nm		
		440	< 5.05%	93.4 BC	98.9 A
4	Blanched	410 - 440	< 0.3250% / nm		
		590 - 620	> 0.1176% / nm		
	Redskin	520 - 620	< 0.1867% / nm		
		440	< 5.05%	93.4 BC	89.2 C
5	Blanched	450	< 23.785		
	Redskin	520 - 670	< 0.1867% / nm		
		450 - 580	< 0.06269% / nm	96.8 CD	96.4 B
6	Blanched	450	< 23.78%		
		520	< 35.78%		
	Redskin	570	< 11.84%		
		450 - 580	< 0.06269% / nm		
		520 - 670	< 0.1867% / nm	97.2 CD	96.4 B
7	Blanched	520	< 35.78%		
		660 - 670	< 0.0680% / nm		
		450	< 23.78%		
	Redskin	520 - 670	< 0.1867% / nm		
		450 - 580	< 0.06269% / nm		
		660 - 700	< 0.01100% / nm		
		660	< 34.43%	97.6 CD	95.7 B
8	Blanched	450	< 23.78%		
		520	< 35.78%		
		410 - 440	< 0.3250% / nm		
		450 - 500	< 0.07920% / nm		
		590 - 620	> 0.05767% / nm		
	Redskin	560	< 10.46%		
		570	< 11.84%		
		660	< 34.43%		
		680	< 39.08%		
		520 - 670	< 0.1867% / nm		
		450 - 580	< 0.06269% / nm		
		550 - 570	< 0.09550% / nm		
		600 - 610	< 0.2420% / nm		
		660 - 700	< 0.01100% / nm	98.2 D	85.1 C

* Kernels were classified as damaged if they were less than (<) or greater than (>) the relative reflectance or slope values shown.

† Percentages in columns followed by the same letter are not significantly different at P = 0.05.

curves as an alternative method of detecting if two kernels were different (Steel and Torrie, 1980). However, the test was too conservative, since it only compared distributions not line slopes or where minimums and maximums occurred. It was found that slopes and locations of minimums and maximums were critical for correct classification of kernels.

No significant difference in any sensors when classifying undamaged kernels was shown in Table 2; however, the spectrophotometer incorrectly classified significantly less damaged kernels than the other sensors. The wavelengths used to establish minimum and maximum ranges and slopes were subjectively selected by observing the characteristic shapes of damaged and undamaged kernel spectral reflectance curves. Thus, based on the spectrophotometer classification potential indicated in the preliminary results, an objective means of selecting optimal wavelength was used to investigate the potential for improved spectrophotometer classification in the second set of tests.

The second set of tests showed that as few as 1% of the damaged kernels were misclassified when the wavelength ranges and slopes were optimized (Table 6). Generally, wavelengths or ranges in the proximity of those listed in Table 6 gave similar damage classification results.

The third set of tests showed that when the wavelengths were further optimized depending on the wavelength group selected, as few as 1.8% or 0.6% of the damaged and undamaged kernels, respectively, were misclassified. Tables 6 and 7 show that wavelength group 2 correctly classified significantly more damaged kernels than group 1 while undamaged kernels were not significantly affected. Other groups correctly classified statistically similar or significantly more damaged kernels, but required more wavelengths to do so and, generally, correctly classified less undamaged kernels.

While all these sensors classified kernels with different accuracies, they should each classify kernels more consistently than human inspectors. This comparison will be made in future research as the project moves towards developing a commercial sensor for use in all peanut grading rooms.

Conclusions

Classification of damaged and undamaged peanut kernels using a black and white machine vision system, two colorimeters, and a spectrophotometer showed the potential for development of objective classification procedures. In conclusion, (1) data from the spectrophotometer resulted in significantly more damaged kernels correctly classified when compared to the other sensing methods evaluated. In initial tests, the machine vision system, contact colorimeter, non-contact colorimeter, and spectrophotometer misclassified 37.3, 20.9, 14.2, and 5.9%, respectively, of the damaged kernels while all undamaged kernels were correctly classified; (2) further analysis of the spectrophotometer data showed that more optimum selection of wavelengths resulted in about 98% of the damaged kernels and about 99% of the undamaged kernels correctly classified.

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