Accuracy and Feasibility of Determining Single Peanut Kernel Moisture Content[1]

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ABSTRACT

The accuracy of a single peanut kernel moisture meter (SKM) was determined on peanuts with moisture contents (mc) from 4 to 50%. Results indicated a significant difference between calibration curves determined over the 4-12% mc range and the 4-50% mc range. No mechanical failures of the SKM occurred; however, excess residue build-up on the SKM rollers affected the moisture meter accuracy. Correlation coefficients for average and single kernel moisture calibration equations were 0.88 and 0.91, respectively, for field cured peanuts over the range of 4 to 12% mc. Procedures for integrating the SKM into the present farmers stock grading process are discussed.

Key Words: Moisture content, dc conductance, quality, peanuts, roasting, shelling, curing, storage.

All U. S. peanuts (*Arachis hypogaea* L.) are inspected for quality before farmer marketing and again before peanuts are used in food products. To insure peanut quality and to minimize inspection costs, the U. S. peanut industry is recommending improvements to increase grading accuracy and decrease equipment and labor costs. These requests are in response to increasing foreign export competition and domestic consumer demands for quality. To address domestic and export needs, recent meetings of peanut industry representatives, consisting of farmers, shellers, blanchers, manufacturers, and inspection service personnel, resulted in identification and prioritization of needed improvements (12). One of the suggested improvement that has the potential of impacting peanut quality as well as reducing inspection cost and labor is the measurement of single kernel moisture content.

Present peanut grading procedures include sampling each of the approximately 400,000 trailers of farmers stock peanuts marketed each year. The price received for farmer stock peanuts is determined primarily from the grade, or quality, factors. Quality factors affecting price include the percentage of moisture, sound mature kernels, oil stock kernels, damaged kernels, undamaged splits, loose shelled kernels, and foreign material (3). Farmers stock peanuts cannot be marketed if average moisture contents are above 10.49%. The moisture content of approximately 200 g of shelled peanuts is measured using a Steinlite or DICKEY-

[1]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be available.

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John Grain Analysis Computer (GAC) moisture meter which determines moisture content based on the temperature, weight, and dielectric properties of the peanuts. These meters give an average moisture content for the sample and, therefore, cannot determine whether a load of peanuts contains kernels with a wide distribution of moisture contents, which is an indication of improper curing. Improper curing may result in some peanuts being over dried, while others may not have been dried to the point where they can be properly stored. Either of these conditions reduces peanut quality. In addition, the inability of the presently used meter to detect single kernel moisture necessitates testing of individual trailers of peanuts for moisture content. However, the Federal State Inspection Service (FSIS) has suggested that one combined sample from two or more trailers from the same field could be inspected if the moisture distribution of the single kernels were known. Determining this moisture distribution in a representative sample would detect improper curing or the need for additional curing. This ability to inspect a composite sample from two or more trailers may decrease the cost and labor required to inspect peanut samples, assuming a sample size similar to the present size predicts single kernel moistures with acceptable accuracy.

Warehouse, sheller, and roaster representatives have also expressed interest in measuring single kernel moistures (7, 11). Loads with acceptable average moisture contents which contain high moisture single kernels should not be stored or should be stored separately since high moisture kernels are likely to mold and develop aflatoxin and other storage problems. Smith and Davidson (13) reported that peanuts with average moisture contents of 10% will enter the danger zone for *A. flavus* if individual pod moisture contents vary greatly. Shellers realize that the ability to identify loads with low or high moisture peanuts going into a shelling plant should provide a better prediction of shelling outturn, thus optimizing profits. Detecting single kernel moistures in roasting ovens may aid in controlling oven temperatures and air flow rates. Therefore, the potential of a single kernel moisture meter to aid in proper curing, storage, shelling, and roasting of peanuts warrants research into methods and procedures for measuring moisture contents of single peanut kernels. The objective of this research was to determine whether a commercially available moisture meter could be used to determine the single peanut kernel moisture contents. Specific areas addressed were accuracy of the meter and the cost and time associated with determining the moisture content of single kernels using the present bulk moisture sample size.

Previous researchers have shown that single kernel moistures of commodities such as corn, soybeans, and peanuts, can be determined with acceptable accuracy. However, a commercial meter for detecting single kernel moistures in peanuts has not been tested. Hutchison and Holaday (4) used electrical resistance to measure the individual moisture content of peanuts as they were crushed between two metal rollers. A commercial instrument was not developed. Kandala and Nelson (6) developed a technique to nondestructively measure peanut kernel moisture using a parallel plate capacitor. They determined single kernel moisture within ± 1% on 97% of the kernels that were in a range of 5 to 15% moisture. Nelson et al. (8) further tested the technique developed by Kandala and Nelson (6) and reported a standard error of performance of 0.5% moisture content when compared to the standard oven moisture method for peanuts in the range of 5-15% moisture. They noted that a practical instrument utilizing their method for single peanut kernel moisture measurement needed to be developed.

Nelson *et al* (10) compared dc conductance, RF impedance, microwave and NMR methods for single kernel moisture measurement in corn (*Zea maize* L.). All four methods provided moisture measurements with standard errors of performance less than 1% moisture content. The dc conductance, RF impedance and microwave cavity measurements required only fractions of a second to make measurements, while the NMR measurements required several seconds per corn kernel. The authors noted that less expensive measurements equipment and circuits would have to be developed and designed for practical single kernel testing utilizing RF impedance, microwave cavity, and NMR techniques. They noted that conductance techniques could become commercially available with minor design changes.

Nelson and Lawrence (9) evaluated a crushing-roller conductance instrument for single kernel corn moisture measurements. The instrument, with appropriate design modification to the feeder, was deemed suitable for detecting corn lots of mixed moisture content when moisture contents of the blended lots differed by 2% or more.

Methods and Materials

Two Shizuoka Seiki Company Model CTR-160-A single kernel moisture meters (SKM) were obtained from DICKEY-john Corporation. The SKM measures the dc resistance of single kernels being crushed between two counter rotating rollers to predict the moisture content of kernels. The ambient temperature is compensated for by the meter. The SKM had been tested and calibrated for use with corn and soybean kernels (5) but had not been used for peanuts. To calibrate the SKM for specific commodities, a range of reference values are obtained from single kernels and linearly regressed against oven moisture values (Fig. 1). The SKM accepts only linear regression calibration coordinates.

The accuracy of the SKM was evaluated in two different studies (Table 1). In the first study, a SKM (SKM #1) was used to test peanuts that had been rehydrated. Kernels were rehydrated by immersion in water for various lengths of time to give a range of moisture contents and were tested approximately one hour after immersion. This allowed testing of the meter when field-cured peanuts could not be obtained. In the second study, a

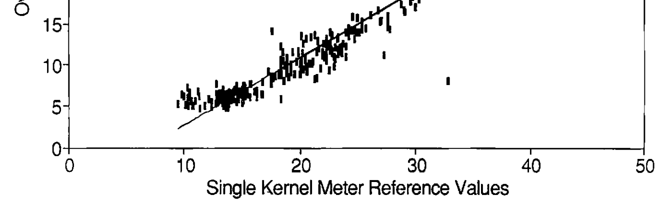

Fig. 1. Single kernel moisture meter calibration curve generated by comparing single kernel meter reference values to oven moistures for field cured peanuts. The linear regression y = 0.82X - 5.51 has a correlation coefficient of 0.96.

Table 1. Ranges of moisture contents used to test the accuracy of two single kernel moisture meters[1].

Study #1	No. of samples	Oven moisture range %
Avg. moisture	56, 180 g samples	5.7-22.9
Single kernel moisture	350 single kernel samples	4.9-32.9
Study #2		
Avg. moisture	32, 195 g samples	5.8-10.8
Single kernel moisture	330 single kernel samples	4.6-49.1

[1]Rehydrated peanuts were used to obtain the moisture samples in study #1; whereas, field cured peanuts provided moisture ranges for study #2. Kernel size ranged from about 0.25 to 1.0 g.

second SKM (SKM #2) was tested on farmers stock peanuts that were field or wagon cured. Kernels were tested immediately after shelling. All moisture contents are expressed in percent, wet basis. Oven moistures of whole and crushed kernels were determined in accordance with the ASAE standard for whole kernels by drying at 130 C for six hr (1). The SKM roller gap was set at 2 mm. Whole Florunner peanuts, regardless of size, were used throughout this research.

In the first study, initial tests evaluated the accuracy of the SKM when determining average, not single kernel, moisture content. This test also determined whether whole-kernel oven drying procedures are reliable for kernels crushed in the SKM. Fifty-six samples of about 400 kernels (approximately 180 g) each, ranging in average moisture content from 5.7 to 22.9%, were obtained by rehydrating shelled kernels. One hundred kernels from each sample were passed through the SKM at a rate of about 1 kernel per second and then the crushed kernels from each sample were oven dried to obtain an average moisture. The approximately 300 kernels remaining from each sample were oven dried without crushing, and this oven moisture was compared with the oven moisture determination from the crushed kernels.

Subsequent tests in the first study evaluated the accuracy of the SKM is measuring single kernel moistures by testing of 350 single kernels ranging in moisture from 4.9 to 32.9%. Each kernel was hand-fed into the SKM, the moisture content of each kernel measured with the SKM, and the residue from each kernel dried for an oven moisture determination.

In the second study, 195-g samples of peanuts were collected from 32 farmers stock loads at farmer marketing during the 1990 harvest season for the average moisture accuracy tests. The average moisture content of each 195-g sample was measured with the SKM immediately after shelling, and all whole kernels, regardless of size, were used. Kernels were fed into the SKM at a rate of about 1 kernels per second. Average SKM moisture content ranged from 5.8% to 10.8%. The residue from each sample was then oven dried. Single-kernel moisture measurement accuracy was determined by hand-feeding single-kernels into the SKM, measuring the single-kernel moisture with the SKM, and then oven drying the residue from each kernel. About 330 kernels, ranging in moisture from 4.6% to 49.1%, from 7 loads were tested for the single kernel accuracy tests.

Statistical analyses were conducted on all samples and also on only those samples with less than 12% mc. Emphasis was placed on determining the SKM accuracy in the 4-12% mc range, since most peanuts arrive at the buying points with less than 12% average moisture. It is important to identify loads with high moisture peanuts; however, the precision in predicting those high values is not critical. Precision is important when testing peanuts with less than 12% mc. Averages, slopes, intercepts and correlation coefficients were compared to determine statistical significance by procedures explained by Steel and Torrie (14). Unless otherwise noted, all statistics resulted from SKM reference values regressed against oven moisture contents. Figure 1 shows an example of single kernel reference values versus oven moistures.

Results and Discussion

SKM Accuracy

Test to compare oven drying of whole-kernel and crushed-kernel samples showed there is no significant difference (P= 0.05) between regression equations predicting moisture contents of oven dried whole kernels or oven dried crushed kernels. Thus, standard whole kernel drying procedures were considered valid.

The crushed and whole kernel regression equations were $y = 0.684 X - 2.22$ and $y = 0.682 X - 2.19$, respectively. The correlation coefficients were 0.98 and 0.97 for the crushed and whole kernels, respectively.

The SKM calculates an average moisture content by adding all kernel moisture contents together and dividing by the number of kernels measured. Thus, the average moisture content is unweighted since a small kernel contributes as much to the average moisture as a large kernel. A paired observation test (14) compared the unweighted moisture content mean to the mean weighted with individual kernel weights (Table 2). Results showed that unweighted and weighted means were not significantly different ($P = 0.01$) with an average difference of 0.02% mc. The samples used in the comparison consisted of single kernels used in the single kernel moisture calibration tests in the second study. Each sample originated from each of seven farmers stock lots.

Rehydrated peanuts were used to evaluate SKM #1; whereas, field cured peanuts were used to evaluate SKM #2. Table 3 shows significant difference between the two meters and also between measurements taken on rehydrated and field cured peanuts with the GAC. Thus, since the single kernel meters and the GAC calculate moisture content based on the electrical properties of the peanuts, it is assumed that rehydrated peanuts had different electrical properties than field cured peanuts. Other research (15, 16) has shown that freshly moistened material conducts more electricity than equilibrated material. This concept is supported by Table 3 which shows that, for the SKM, rehydrated curve slopes are significantly lower than field cured curve slopes. Thus, for a given increase in oven moisture, a larger change in rehydrated SKM values was measured compared to the change in field cured SKM values. For example, a 2.48% mc versus 1.96% mc increase in SKM reference values for rehydrated and field cured peanuts, respectively, predicted a 1% mc increase in oven moisture. In addition, the SKM correlation coefficient for rehydrated peanuts was significantly less ($P = 0.05$) than for field cured peanuts indicating significantly less correlation of rehydrated peanut moisture content data. If the single kernel moisture meter is calibrated using rehydrated peanuts and used to predict moisture contents of field cured peanuts, then a maximum error of about 0.6% moisture may occur over the range from 5 to 10% moisture.

There were significant differences ($P = 0.05$) between intercepts of equations used to predict single kernel and average moistures (Table 4). Although the intercepts were significantly different, the relative values of the single kernel and average moisture intercepts are opposite in relationship for the two SKM's. However, above about 3% mc, which is the mc above which all kernels were tested, the single kernel moisture values were consistently less than the average moisture at any given reference moisture. If one equation is used to predict both single kernel and average moistures, then an error of about 1% moisture can occur over the range from 5 to 10% moisture.

The average and single kernel moisture prediction equations show that, above about 3% mc, for a given oven

Table 2. Paired observation statistical test on moisture content (mc) averages calculated from weighted and unweighted single peanut kernels.

Sample No.	Unwtd. Avg. mc (%)	Wtd. avg. mc (%)	Std. dev. of unwtd. Avg. mc (%)	Unwtd.-Wtd. Avg. mc (%)	Range mc (%)	Range dry wts. (g)	No. kernels	R[1]
1	5.07	5.04	0.68	0.03	4.84- 7.23	0.23-0.74	20	0.235
2	6.78	6.77	0.87	+0.01	4.63-10.78	0.22-0.99	100	0.114
3	10.29	10.35	1.50	-0.06	5.83-12.60	0.25-0.68	20	0.208
4	10.99	11.03	1.44	-0.04	8.66-13.42	0.41-0.82	49	0.103
5	16.24	16.32	4.04	-0.08	11.54-31.73	0.18-0.79	50	0.314
6	16.28	16.23	6.26	0.05	8.27-31.41	0.29-1.04	40	0.315
7	26.81	26.84	4.56	-0.03	16.62-49.12	0.26-0.80	51	0.279
		Avg. difference[2]		-0.02				

[1]Correlation coefficient of single kernel dry weights to oven moisture content.

[2]The 99% confidence interval (-0.085 to 0.050) for the average difference includes 0, thus the hypothesis that the unweighted minus the weighted average mc equals zero (H_0: unweighted mean - weighted mean = 0) cannot be rejected.

Table 3. Comparison of regression equations for moisture measurements of rehydrated peanuts and field cured peanuts[1].

	Slope[1]	Intercept[1]	r[1]	No. samples
SKM (<12% mc)[2]				
Rehydrated (SKM #1)	0.403(S)	1.12(NS)	0.82(S)	222
Field cured (SKM #2)	0.511	-0.661	0.91	189
GAC (<12% mc)[2]				
Rehydrated	0.931(NS)	0.623(S)	0.96(NS)	38
Field cured	0.986	0.104	0.95	32

[1]Rehydrated and field cured slopes, intercepts, or correlation coefficients (r) are significantly different (S) or not significantly different (NS) at P = 0.05.

[2]Moisture contents (mc) were determined with a single kernel moisture meter (SKM) and average mc with a DICKEY-john grain analysis computer (GAC) and compared to oven moistures.

Table 4. Comparison of moisture content prediction equations for single kernel and average moisture contents below 12% using two single kernel moisture meters (SKM) evaluated on separate lots.

	Slope[1]	Intercept[1]	r[1,2]	No. Samples
SKM #1				
Average moisture	0.473(NS)	0.947(S)	0.93(S)	38
Single kernel moisture	0.403	1.12	0.82	222
SKM #2				
Average moisture	0.520(NS)	0.248(S)	0.88(NS)	32
Single kernel moisture	0.511	-0.661	0.90	189

[1]Average moisture and single kernel slopes, intercepts or correlation coefficients (r) are significantly different (S) or not significantly different (NS) at P = 0.05.

[2]Each correlation coefficient is significant at P = 0.05.

moisture content the SKM registered lower average moisture than single kernel moisture. Table 2 does not show that this difference is attributed to weighted versus unweighted average errors. However, a comparison of the average moisture content of the first 160 and last 160 kernels from 24 samples revealed that the meter registered a significantly lower reference mean for the latter 160 kernels (P = 0.05). The reference means of the first 160 and last 160 kernels were 13.2042 and 12.9635, respectively, with a least significant difference of 0.1666. Each sample required only about 7 minutes to analyze by the SKM, thus, this lower moisture indicated by the meter is not likely due to actual drying of the peanuts. Therefore, some bias is occurring in the SKM over time as each sample is tested. The only procedural difference between the single kernel moisture tests and the average moisture tests was the rate at which kernels were fed into the meter. For single kernel tests, kernels were slowly hand-fed into the meter so that the residue from each kernel could be collected, weighed, and dried. For average moisture tests, kernels were fed at a much faster rate and residue from all kernels from each sample was collected, weighed, and dried together. This faster feeding rate may not have allowed the rollers which crushed the kernels to adequately clean off between individual kernels, thus biasing subsequent moisture readings. This difference in kernel feeding rates might explain the differences in calibration equations obtained for average- and single-kernel moisture content measurements with the SKM.

The SKM only has provision for calibration with a linear equation; however, a quadratic equation was fit to the data to see if a significant improvement in predicting oven moistures could be achieved. Table 5 shows that a slight improvement in correlation coefficients resulted when the quadratic fit was compared to the linear fit; however, this increase in correlation coefficients was not statistically significant (p = 0.05). The comparison between a quadratic and linear fit was made on all single kernel moisture data and also on those values less than 12% oven moisture.

Table 5. Comparison of quadratic and linear fits of single kernel moisture reference data versus oven moisture.

Range	Equation	r[1]	n
SKM #1			
4-35%	$y = 3.28 + 0.1422X + 0.0095 X^2$	0.848	350
	$y = 0.641X - 2.38$	0.844	350
4-12%	$y = -1.76 + 0.7314X - 0.0091 X^2$	0.831	222
	$y = 0.403X - 1.12$	0.824	222
SKM #2			
4-50%	$y = 2.88 + 0.0579X + 0.0148 X^2$	0.966	330
	$y = 0.820X - 5.51$	0.956	330
4-12%	$y = 3.57 - 0.0055X + 0.0151X^2$	0.910	189
	$y = 0.511X - 0.661$	0.904	189

[1]Quadratic and linear correlation coefficients (r) for each single-kernel moisture meter (SKM) are not significantly different at P = 0.05.

Kernels with moisture contents from about 4 to 50% were tested with the SKM. However, Table 6 shows that regressions run on data from 4-12% mc were significantly different from regressions run on data from 4-50%. Thus, if accurate predictions of moisture contents is more important for a narrow range than for a wide range, then a calibration curve developed over the narrow range should be used.

Table 6. Comparison of the calibration curve for all single-kernel moistures versus the curve for only those kernels with less than 12% moisture content (mc). Results are shown from two single-kernel moisture meters (SMK).

	Slope[1]	Intercept[1]	r[1]	No. samples
SKM #1				
4-12% mc	0.403(S)	1.12(S)	0.82(NS)	222
4-35% mc	0.641	-2.38	0.84	350
SKM #2				
4-12% mc	0.511(S)	-0.661	0.90(S)	189
4-50% mc	0.820	-5.51(NS)	0.96	330

[1]Slope, intercepts, and correlation coefficients (r) are significantly different (S) or not significantly different (NS) at P = 0.05 when comparing the two ranges for each SKM.

Table 7 shows the ranges of moisture contents in all composite samples of peanuts used in test #2. Diener and Davis (2) reported that optimal moisture content for growth of *A. flavus* is above 10%. Trailers 2, 19, and 26 all had kernels above 10% mc. However the standard deviation for Trailer 2 indicates that only about 0.05% of the kernels were greater than 10% mc. Trailers 19 and 26 had more than 15% of the kernels over 10% mc as indicated by their standard deviations. Thus trailers 19 and 26 possibly should have been dried further or segregated since *A. flavus* and subsequent production of aflatoxin is likely to occur during storage of these peanuts.

Table 7. Moisture contents, percent wet basis, of 195-g samples from 32 loads of farmers stock peanuts as measured using a calibrated single kernel moisture meter[1].

Sample	Avg.	Min.	Max.	Std. dev.
1	5.53	3.94	8.03	0.60
2	7.61	5.42	10.12	0.87
3	5.89	4.14	7.67	0.60
4	5.27	3.94	6.49	0.50
5	5.47	3.94	7.62	0.50
6	5.18	3.94	7.31	0.51
7	6.03	4.35	7.92	0.68
8	5.24	3.94	6.90	0.45
9	6.69	4.04	9.05	0.89
10	4.98	4.04	7.77	0.35
11	4.97	3.94	7.72	0.54
12	5.86	4.19	9.36	0.56
13	5.79	4.14	8.28	0.66
14	6.36	4.50	9.61	0.86
15	5.03	3.94	8.54	0.50
16	8.17	3.94	9.46	0.75
17	5.42	3.94	8.28	0.47
18	8.05	5.22	9.97	0.82
19	9.04	4.81	18.81	1.74
20	5.02	3.94	6.19	0.32
21	5.08	4.19	6.90	0.35
22	4.94	3.94	8.33	0.44
23	6.34	4.60	7.92	0.70
24	5.59	4.35	9.82	0.60
25	4.94	3.94	6.29	0.47
26	9.42	6.90	14.21	0.97
27	5.57	3.99	7.62	0.66
28	6.73	4.60	8.74	0.86
29	6.09	3.94	8.08	0.68
30	6.83	4.81	9.51	0.80
31	4.88	3.99	6.03	0.35
32	4.70	3.94	5.98	0.39

[1]The calibration equation $Y = 0.511X - 0.661$ was used to convert single kernel reference values.

SKM feasibility

Modifications to the present farmers stock grading procedures are needed if the SKM is to be integrated into the grading system. A separate or larger sample may need to be shelled, since the damage detection procedure splits and breaks kernels during the internal damage analysis. The mc of the small broken pieces would not be determined with the SKM. If a separate sample is used to determine single kernel moisture, then a 750-g sample of pods instead of the present 500-g sample would be shelled. The larger sample size assumes a single-kernel moisture sample size equivalent to the present bulk moisture sample size of about 200-g. Approximately 200-g of the shelling outturn would be used to determine single kernel moisture and the remainder used to determined the normal grade factors. Since grade factors are calculated based on pod weight, the appropriate weighting factors must be used to account for the kernels removed for single kernel moisture testing. An alternative procedure is to shell a separate 250-g sample for single kernel moisture testing and not change the other grading practices. Current procedures require about 1800-g of pods be removed from each trailer, thus there are enough pods for either of these proposed procedures.

The GAC which is used in present grading procedures uses about 195 g of peanuts, which is about 420 kernels, and determines the moisture in about 20 sec. The SKM can process about one kernel per second. Thus, about 7 minutes to process the same sample size as used with the GAC. However, single kernel moistures can be determined concurrently with the other grade factors. Thus, the total grading time per sample would not be increased.

The cost of the SKM is about $5,500 versus the GAC cost of about $2,750. Assuming a useful life of 5 years, salvage value equal to 10% of purchase price, and an interest rate of 11%, the SKM would cost about an average of $1400 per year. However, in the interest of peanut quality and labor cost, the benefit of determining the single kernel moistures may outweigh any additional cost associated with implementing the single kernel meter. For example, storage of the peanuts with moistures greater than 10% mc would augment the conditions for *A. flavus* growth and the subsequent formation of aflatoxin (13). Thus, the possibility of a shelled stock lot of peanuts being rejected because of aflatoxin would increase. Shelled stock lots with aflatoxin levels greater than established thresholds must be blanched to lower aflatoxin levels. Assuming that segregating farmers stock loads according to single kernel moisture contents prevented one 20,000 pound shelled stock lot from being rejected because of aflatoxin, at a blanching cost of $0.05 per pound, the potential savings to peanut shellers would be $1,000. Thus, avoiding the blanching of a single lot of shelled stock peanuts each year would cover most of the increased cost associated with the SKM. In addition, the quality of peanuts reaching the consumer should increase since mixed loads or improperly cured loads of peanuts would be identified and handled appropriately. This is but one example of how the SKM could be used to save money and improve grading accuracy.

Summary

Field cured and rehydrated peanuts from 4 to 50% mc were used to test the accuracy of a SKM. There were significant difference between field cured and rehydrated calibration curves. There were also significant differences between calibration equations developed over the 4-12% mc and 4-50% mc ranges. Biasing of moisture content measurements occurred as residue built up on the SKM rollers, thus, improved cleaning of the rollers is needed. With minor procedural changes, the SKM could be implemented in the present farmers stock grading system.

The significance of all correlation coefficients indicate that the SKM can be used to accurately predict single kernel moistures. This information can potentially be used to improve curing, storage, shelling, and roasting practices resulting in increased profits and improved peanut quality. Future research should include sample size and cost feasibility assessments in each of these areas.

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