Weighing Platforms for Automated Peanut Curing[1]

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ABSTRACT

An instrumented weighing platform was developed for in-process moisture determination of curing peanuts and a field study was conducted to evaluate its performance. The design and evaluation of the weighing platform are described in detail. Statistical analysis of the difference between the final moisture content predicted by the platform and the actual kernel moisture content of cured peanuts indicated that the weighing platform accurately predicted final kernel moisture content. The weighing platform system can easily be incorporated into existing curing facilities. It has the potential to reduce the number of samples required by conventional curing techniques and, by maintaining better moisture content control reduce the incidence of overcuring or undercuring.

Key Words: Peanut, curing, automated, moisture content, drying

Peanut (*Arachis hypogea* L.) curing is one of several important steps in the peanut production process. An important problem associated with conventional forced air peanut curing techniques is overcuring or undercuring the peanuts. Excessive amounts of splits (split kernels) and baldheads (the testa or "skin" is removed from the kernel) can develop during shelling if peanuts are overcured to a moisture content below 8%. Undercuring resulting in final moisture contents above 10% can encourage the growth of molds which produce aflatoxin.

Forced-air curing involves attaching a curing unit to the trailer plenum and forcing heated air up through the trailer's false bottom into the peanut mass. The peanuts are sampled to determine their moisture content throughout the curing process (usually 4 to 10 times). This sampling continues until the peanuts reach an average moisture content in the range of 10%, at which time forced air curing is terminated, and the peanuts are ready for storage.

Ideally, peanut moisture content should be determined by taking random samples throughout the trailer at various depths and averaging the results. However, moisture content is most often calculated from grab samples collected from the top of the trailer. Because the drying front moves from the bottom of the trailer to the top, the peanuts at the top will always be wetter than the ones at the bottom. If curing continues until peanuts on the top dry to 10%, the peanuts on the bottom will be overcured.

To prevent overcuring, Blankenship and Davidson (1979) developed an electromechanical system for laboratory peanut curing which automatically cut off when the prescribed average moisture content was reached. They also tested a similar electronic system for automatic monitoring and cutoff of full-scale peanut curing equipment Blankenship and Davidson (1984). In that test, three load cells were placed under the axles of a trailer to obtain the weight during curing. The curing process was terminated when the peanut/trailer weight associated with the desired final moisture content was reached. They concluded that a curing system of this type would reduce moisture sampling time considerably during the curing process and reduce the potential of overcuring peanuts. They also noted that this type of system offers better moisture control than obtained with conventional methods and, consequently, will maintain peanut quality. The time and labor required to raise the trailers and the associated potential safety hazards make this approach unfeasible for a commercial curing facility.

Incorporation of this type of automated system into the curing operation requires a simple and economical weighing apparatus. The weighing apparatus must be designed so that it can be incorporated into existing curing stations without creating additional labor demands for the operators. The weighing system must also be simple to use and able to withstand the harsh environmental conditions encountered at commercial curing facilities.

With these needs in mind, this study was initiated with the aim of developing a functional, simple, and economical system for determining peanut moisture during the curing process. Four specific design constraints initially established were that the developed system must: a) determine moisture contents of curing peanuts by passively measuring a physical property of the peanut/trailer system; b) be easily incorporated into existing curing facilities; c) have the potential to reduce the number of samples required by conventional curing techniques and; d) reduce the incidence of overcuring or undercuring. This paper describes the weighing system that was developed and its performance in the field.

Materials and Methods

Preliminary design evaluations showed that a bending beam weighing platform could be used to continuously weigh peanut trailers during the curing process (Vellidis *et al.*, 1990; Perry *et al.*, 1991). The platform was designed to be placed in the curing station such that it supported the rear wheels of a tandem-wheel trailer during curing (Fig. 1). Strain gages were

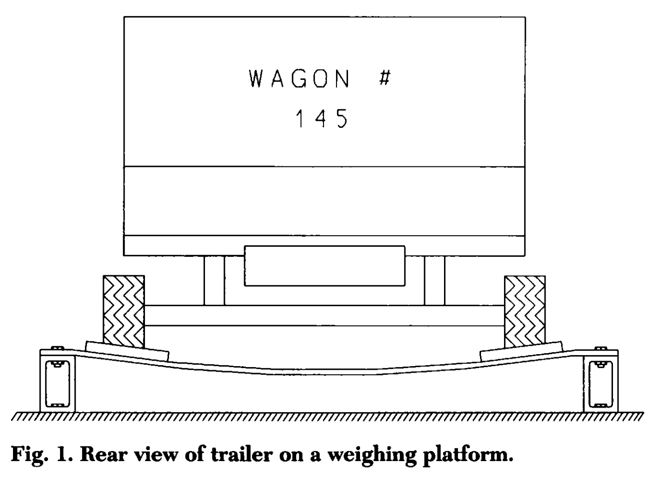

Fig. 1. Rear view of trailer on a weighing platform.

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[3]Steinlite model G moisture meter used by FFM for moisture content measurements and housed in the FFM yard traffic control shed.

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mounted on the platform to measure deflection resulting from the weight of the trailer.

The bending beam platform was a steel plate (244 cm x 61 cm x 1.6 cm) supported on each end by rectangular steel tubing (7.6 cm x 12.7 cm x 0.5 cm) (Allgood, 1991). The rectangular end supports were securely fastened to the concrete floor with masonry bolts and the platform was bolted to the supports. Due to the physical limitations of the test site, peanut trailers were backed onto rather than pulled across the platforms. Steel ramps were used to facilitate loading the trailers onto the platforms and back stops were added to prevent trailers from being backed off the platforms (Fig. 1).

The weight of a trailer's rear axle acting on the platform caused the steel plate to deflect downward thus creating a measurable strain within the plate. To measure this bending strain, four 350 ohm strain gages (Allgood, 1991) were applied perpendicular to the central bending axis. The gages, spaced 1.3 cm apart, were applied at the center of the steel plate (Fig. 2) with two on top (compression) and two on bottom (tension). The four gages were wired into a Wheatstone bridge circuit for maximum output and temperature compensation (Omega, 1989). The strain gage circuit was supplied with +5 volt excitation from a DC power supply and returned a millivolt signal proportional to the strain in the platform which was measured with a data acquisition system.

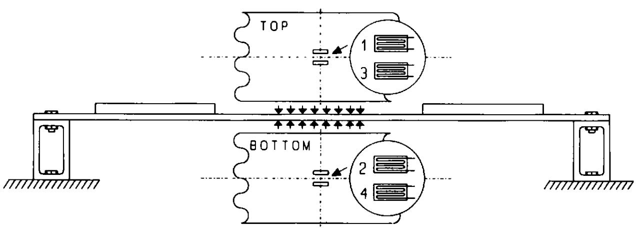

Fig. 2. Location of the 4 strain gages on a weighing platform.

The data acquisition system consisted of an IBM PC compatible computer linked to an OPTO22 Brainboard system via an RS422 communication link (Allgood, 1991). The software for the system was written in Microsoft Quickbasic 5.0 and compiled into a stand alone executable program for faster operating speed. The primary function of the program was to communicate with the OPTO22 Brainboard for data acquisition. The program was designed to do the following tasks:

1) Send and receive data from the Brainboard.
2) Restart itself without loss of data after a power outage.
3) Continue to monitor the weighing platforms after a power outage.
4) Monitor each curing station independently.
5) Monitor all weighing platforms during the curing process.
6) Predict the current moisture content within each trailer.

Prior to each manual start of the system, the identifying number of each occupied platform (curing station) was entered. These platforms were then activated by the program.

Platform installation and calibration

Three platforms were installed at Farmers Fertilizer and Milling (FFM) peanut shelling facility in Colquitt, Georgia. The Colquitt facility is FFM's largest buying point and has approximately 125 curing stations which are in full operation during the peak of the peanut harvesting season. The test site chosen for this research project is located adjacent to the main peanut receiving area and consisted of a curing shed with ten curing stations. Each station had its own individual curing unit consisting of an axial blower fan with LPG burner which attached to the plenum of the peanut trailers. The shed has a concrete floor that sloped slightly to the rear. Due to a drainage ditch behind the shed, trailers were backed into place under the shed.

The OPTO22 Brainboard and the main host computer were stationed in an adjacent instrumentation building. All wiring from the platforms was routed to this building. An electronic platform scale (4545 kg capacity) was installed adjacent to the curing shed to accurately weigh the trailers before they were placed onto the platforms.

The process of calibrating the platforms consisted of placing loaded peanut trailers of known weight on each platform and recording the strain produced. The strain readings were plotted against the true weight value to obtain a linear equation that related measured strain to platform load. The equations were developed using linear regression and produced R^2 values in the 90 and 99% range (Allgood, 1991).

Platform evaluation

The curing study was conducted from 28 August to 19 September 1991. Forced air curing began when a grower delivered the peanuts to the buying station. The trailer was identified with the grower's name and date and a sample was removed from the top of the trailer by the drying crew for initial moisture content determination with the "SHED" moisture meter[3]. If a weighing platform was available, the trailer was transported to the curing shed by tractor where it was first pulled across the electronic platform scale to obtain the rear axle weight and then positioned in front of the selected weighing platform.

Before a platform could be loaded, it was activated by the computer program and initialized to obtain its unstrained output voltage - a measurement necessary for strain calculation (Allgood, 1991; Omega, 1989). Once unstrained voltage was read, the loaded peanut trailer was backed onto the platform, the distance of the rear wheels from the ends of the platform was recorded, and the appropriate trailer data entered at the program prompts. These data included rear axle weight, initial kernel moisture content, current time and date, and trailer identification number.

Following data entry, the program began data acquisition and the dryers were manually started. The program's scan loop routine sampled all currently active platforms at 5 minute intervals during the curing process. When the routine sampled a platform, it read the input and output voltages of the Wheatstone bridge circuit to calculate strain. The strain value was in turn used to calculate the current weight of the rear axle from the calibration equations.

Once current weight was known, average moisture content was calculated from the difference of initial and current rear axle weight. Current moisture content was then saved to a platform-specific data file and the next active platform was scanned. After all platforms had been read during the current scan loop routine, the program waited for the next scan time.

At various times during curing, the dryer operator removed samples from the top of the trailer to ascertain if the peanuts had reached the desired moisture content. This sampling was repeated until the kernel moisture content at the top of the trailer was approximately 11 percent. The curing process was terminated at this moisture content because the dryer operators felt that when the top of the trailer was at 11%, the average moisture content would be at or below the acceptable standard of 10.49% (PAC, 1988).

When the trailers finished curing, they were removed from the platform and graded. The grading process involved taking random samples from the trailers and evaluating them according to federal peanut standards which include a final moisture content and foreign material content determination.

The operation of the weighing platforms was evaluated by comparing actual peanut kernel moisture contents to moisture contents predicted by the platforms for each trailer of peanuts cured on the platforms. Each platform was tested with 13 or 14 trailers (40 total). The data for kernel moisture content were obtained from three different sources. The first source was the moisture content of the samples that the dryer operators obtained during the curing process. These samples were measured with the "SHED" moisture meter and the resulting moisture contents were recorded along with the time the samples were taken. The second source was the final kernel moisture content obtained from the USDA grading process. This moisture value, which was determined using a Dickey John GAC II moisture meter, was recorded on the grading sheet along with the other grade data. The third source of kernel moisture content data was the oven dried samples that were obtained from trailers every three hours during the curing process by taking three probed core samples (center front, center middle, and center rear) from the trailer. The entire sample was shelled, divided into three 75 gram oven samples, and dried at 150°C for three hours (Blankenship and Davidson, 1979).

Four curing parameters initially identified as having the greatest potential impact on platform accuracy were: 1) wheel placement on platform; 2) beginning moisture content; 3) foreign material content; and 4) elapsed time before grading. Wheel placement on the weighing platforms was observed to affect the strain readings during calibration and so the platforms were calibrated with trailers whose wheels were centered on the platforms. Because this condition was not easily replicated during the actual test, wheel placement was evaluated as a variable that could potentially affect final accuracy.

Beginning moisture content was also an influencing factor because when the initial moisture content is inaccurate, an error is introduced into the moisture prediction algorithm and carried throughout the moisture prediction process.

Foreign material has always been a problem in the curing process. Dirt, sticks, stalks and gherkins (small species of wild cucumber) will loose their moisture during the curing process as well as the peanuts. The curing system assumes this extra water as coming from the peanuts, potentially resulting in a inaccurate moisture prediction.

The elapsed time before grading can range from a few hours to more than a day. Most dryer operators allow the peanuts to cool down from the curing process before grading. During the cooling down or coasting process, moisture moves from the kernels to the hulls and then to or from the ambient air. This process will continue until the kernels and hulls come to a state of moisture equilibrium with the surrounding air. The possible error arises when a trailer sits an extended time before grading as compared to one that is graded within hours after removal from the weighing system. The predicted moisture from the weighing platform is at the time of trailer removal. If the trailer is allowed to sit before grading, the actual peanut moisture could change.

Results and Discussion

The operation of the curing system resulted in curing curves being produced for every trailer that was cured on a weighing platform. These curing curves (Fig. 3) were prepared using data from 4 different sources. The PRED (predicted) data set is the continuous moisture measurement as predicted by the weighing platform system and represents the predicted moisture loss from the peanuts during curing. The SHED data set represents the moisture samples that were taken by the curing operators during the curing process. The operators used the SHED data to determine when curing ceased. The USDA data point is the final kernel moisture content measured during the grading process. In Fig. 3, it was actually measured four hours after the trailer was removed from the weighing platform. The OVEN data set represents moisture contents determined from the oven-dried samples.

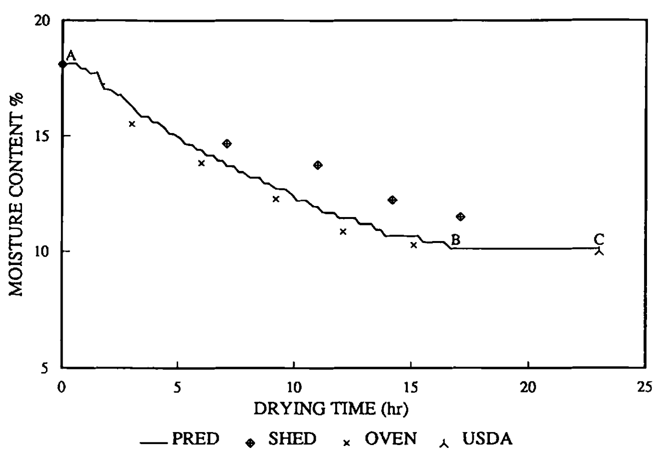

Fig. 3. Typical drying curve obtained for an individual trailer.

The PRED curing curve is composed of two distinct regions. The first region, located between points A and B in Fig. 3, represents the moisture loss from the kernels during the curing process. This process began when the trailer was placed on the platform (point A) and continued until the curing was terminated (point B). The second region on the curing curve represents the time that the trailer remained on the platform after the curing process had been terminated. This region, located between points B (curing termination) and C (trailer removal), ranged from a few minutes to several hours. During this time, the peanuts undergo coasting. Because initially during this process, moisture generally does not leave the trailer but is instead redistributed within it, the weighing platforms register little change in moisture content.

The SHED data points are from moisture samples taken from the top of the curing trailer by the dryer operator. Since the curing front moves from the bottom of the trailer to the top, it is logical that these SHED moisture readings would be higher than the actual kernel moisture data points (OVEN) which are an average over the peanut depth.

Evaluation of platform accuracy

The platforms were evaluated based on how accurately they predicted the final USDA grade kernel moisture content. As the average difference between the PRED (point C) and USDA moisture contents approaches zero, the error of the curing platform measurement decreases. Table 1, which gives a summary of platform performance, indicates that the average moisture difference was within 0.2%. Of the 40 trailers dried, only one (2.5 percent) of the predicted moisture contents missed the USDA grade moisture value by more than 1% (Fig. 4).

Table 1. Individual platform evaluation in terms of final moisture accuracy (%).

Platform Number	Trailers Dried	Average Difference[a]	Standard Deviation	Absolute Minimum Difference[a]	Absolute Maximum Difference[a]	Significance Level
1	14	0.148	0.634	0.10	1.27	0.399
2	13	0.188	0.472	0.10	0.94	0.196
3	13	0.193	0.334	0.00	0.82	0.059

[a] Difference between PRED (at time trailer removed from platform - Point D) and USDA (at grading) moisture content.

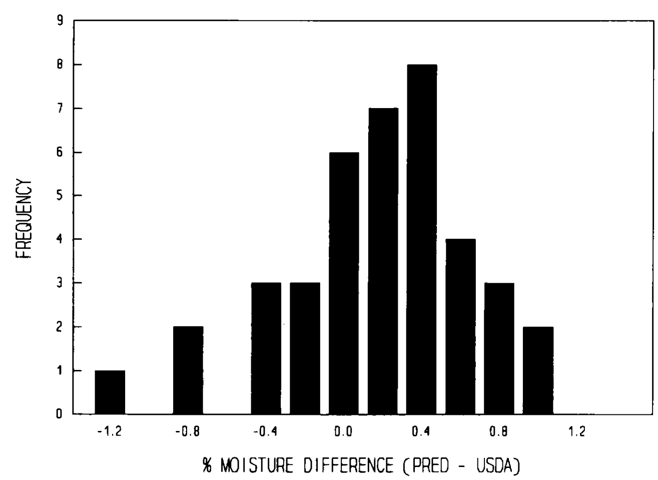

Fig. 4. Histogram of drying accuracy for 40 trailers cured on 3 platforms.

A one sample t-test was performed on each platform to determine if the moisture difference between predicted and actual final moisture values were statistically different from zero. The data for the statistical analysis consisted of the difference between the PRED and USDA final grade moisture for all trailers dried on that platform. At the α = 0.05 level, no significant differences between the predicted and actual moisture contents were found for any of the platforms based on the number of measurements in this test (Table 1). This result indicates that the bending beam weighing platform can be used in future weighing applications.

To test the effects of wheel placement, beginning moisture content, foreign material content, and elapsed time before grading on platform accuracy, a Pearsons product moment correlation analysis was performed between the four parameters and the moisture differences that resulted from each platform. The correlation coefficient (r) is a measure of the strength of linear relationship between two variables y and x. A value of r near or equal to zero implies little or no linear relationship between the two variables. In contrast, the closer r comes to 1 or -1, the stronger the linear relationship If r = 1 or r = -1, all the points fall exactly on the least squares line. Positive values of r imply a positive linear relationship (y increases as x increases), whereas a negative value of r implies a negative linear relationship (y decreases as x increases).

The results of the correlation analysis varied widely between platforms for each parameter (Table 2). This variation was attributed, in part, to the relatively small number of observations for each platform. For the test conditions of this study, wheel placement, beginning moisture content, foreign material content, and elapsed time before grading were not found to have a significant effect on platform accuracy.

Table 2. Correlation analysis of factors affecting platform accuracy.

Platform Number	Wheel Position	Beginning Moisture	Foreign Material	Time Elapsed Until Grading
1	0.153[a] (.602)[b]	-0.444 (.112)	-0.254 (.383)	-0.268 (.354)
2	-0.170 (.596)	-0.117 (.718)	-0.225 (.482)	0.336 (.286)
3	-0.202 (.508)	-0.041 (.893)	-0.250 (.410)	-0.251 (.408)

[a] Correlation coefficient, r
[b] (Significance level)

Cost Analysis

The OPTO22 Brainboard system used in this study was limited to 16 channels so the cost analysis presented in Table 3 was determined for 16 curing stations, each instrumented with an automated weighing platform. For the above configuration, cost per curing station is approximately $600. Because all instrumentation is physically part of the curing stations and not part of the trailers, this cost remains fixed regardless of how many different trailers are used over the life of the system. The system can be expanded beyond 16 curing stations by either purchasing another Brainboard for every additional 16 platforms (expensive), or, by installing one or more 32 or 64 channel multiplexers (lower cost). With either option, the cost per curing station would continue to decrease as the weighing platform system was expanded.

Table 3. Costs for instrumenting 16 curing stations.

Item	Quantity Required	Unit Cost	Total Cost
Platforms	16	$ 350	$ 5,600
Data acquisition system	1	$ 2000	$ 2,000
Strain gages	64	$ 6	$ 384
Microcomputer	1	$ 950	$ 950
Power supply	1	$ 300	$ 300
Cable	400 ft	$ 0.80/ft	$ 320
Total			**$ 9,554**

Summary and Potential Applications

This research project was initiated with the aim of developing a functional, simple, and economical system for determining peanut moisture during the curing process. A weighing platform was developed to monitor water loss from the trailer during curing.

Of the 40 trailers dried, 97% had predicted moisture contents within one percent of the final grade moisture. This accuracy in predicting the final moisture content will allow the weighing system to be incorporated into the curing process to eliminate continuous manual sampling and to perform automatic dryer control. Statistical analysis of the difference between final predicted and actual moisture contents of cured peanuts indicated that at the $\alpha = 0.05$ significance level all the platforms accurately predicted final kernel moisture content.

This study has shown that a weighing platform system, which is able to predict the moisture content of the peanuts during curing, can be incorporated into existing curing stations. This weighing system has the potential to reduce the sampling required to determine when peanuts are dry, maintain better moisture control, and reduce the incidence of overcuring. The future use of this type of weighing system could significantly automate the peanut curing industry. Moisture measurements could be taken throughout the curing process thus eliminating the need for manual sampling. The automated curing system monitors the moisture content of each trailer and can display the moisture values in real time. Control of the curing fan and burner could be incorporated into the system and, when the peanuts are dry, the system would terminate the curing process and signal the dryer operator.

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