Peanut Quality Improvement Through Controlled Curing[1]

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ABSTRACT

Peanut curing must proceed fast enough to avoid mold problems and harvest delays, and yet proceed slow enough to avoid milling quality loss. A new dryer heat control method, termed drying rate control (DRC), was developed to better meet the above criteria. DRC was tested and compared with humidistat control (HC) and conventional control (CC) using a bulk simulation model and laboratory curing tests. Airflow rates of 5, 10, and 15 m^3/min/m^3 were used. Simulation studies incorporated five years of actual weather data from Suffolk, Va. Laboratory curing tests were done on nine lots of peanuts over two years. Average curing times were the same for CC and DRC, but averaged 17% longer with HC. Estimated fuel costs were nearly the same for CC and DRC, but were 14% less for HC. Mold risk, percent splits in the grade sample, and volatile organic matter concentrations were nearly the same for all heater control methods. Percent skin slippage in ELKs, measured with a subjective test, averaged approximately 30% less with DRC and HC as compared to CC. In summary, HC resulted in better peanut quality than CC with lower fuel cost, but increased curing time. DRC resulted in better peanut quality than CC with similar curing time and similar fuel cost.

Key Words: Quality, dryer, curing, skin slippage, energy consumption, peanuts.

The peanut (*Arachis hypogaea* L.) testa has several important functions including protection of the seed embryo from fungal invasion and helping to maintain the physical integrity of the seed. Bell (1984) reported that field emergence was 33% less for bald seed (seed without testa) than for intact seed, even though both seed lots had been treated with a fungicide. Pod yield from individual plants and the percent of sound mature kernels (SMK) were also less for bald seed than for intact seed. Processors report that shelled peanuts containing bald kernels have a significantly greater percentage of split kernels than do shelled peanuts without bald kernels. Split kernels are undesirable due to lack of consumer appeal.

Curing is a critical operation in the post-harvest processing of peanuts. Air conditions must be such that curing proceeds at a rate fast enough to avoid mold growth in peanuts at the top of a trailer. Yet, if curing air humidity is too low, resulting in a drying rate that is too high, the peanut cotyledons of bald kernels will spread apart (Woodward and Hutchinson, 1972). As the seed coat is stressed, there is a tendency for it to loosen from the cotyledons. During subsequent handling, the loosened seed coat may abrade and slip off, resulting in a bald kernel.

Young *et al.* (1982) presented a range of recommended air conditions (temperature and humidity) for curing peanuts. Conditions giving a drying rate lower than the specified range increases the risk of mold growth in the peanuts. Conditions giving a drying rate higher than the specified range may result in an increase in skin slippage. The conventional heater control method for curing (described here as a fixed 8.5 C) allows air conditions that at times gives a drying rate higher than those specified by Young *et al.* (1982), particularly during periods of low ambient air humidity. Alternate heater control methods are needed which will maintain curing air conditions such that the drying rate will be in the desired range.

The objective of this study was to develop and test a heater control method that would result in improved peanut quality without increasing curing time or fuel use. Several lots of peanuts were tested in order to extend the study over different initial peanut moisture contents and maturity stages, airflow rates, and weather conditions.

Materials and Methods

Simulation of Peanut Curing

PEADRY8, a deep bed peanut simulation model developed by Colson and Young (1990), was used to evaluate three different heater control methods (Table 1). In order to calculate temperatures for DRC, data from the graph in Young *et al.* (1982) was used to develop three linear equations to approximate the curve for maximum recommended temperature as a function of humidity ratio. The equations and applicable ranges of humidity ratio are listed in Table 1. Individual simulations were run assuming a dryer was started on 8:00 p.m. on each of 34 days (9/25 to 10/28) using five years of weather data (1987-1991) recorded by the Agro-Environmental Monitoring System (AEMS), USDA-ARS, Suffolk, Va. For the simulation, a deep bed of peanuts (in pods) was divided into ten layers. Drying of the bottom layer was simulated using ambient air conditions adjusted by increasing the dry bulb temperature according to the heater control method being tested.

Drying of the remaining layers was simulated using the exhaust air conditions from the preceding layer. A 15 min. computational interval was used. The simulation was terminated when the mean kernel moisture content for all ten layers was 10%.

Bulk density was assumed to be 210 kg of dry pods per m^3 of dryer volume. Initial pod moisture contents of 25 and 30% were studied. Corresponding kernel moisture contents were 26.0 and 31.8%, respectively. Percent kernels was 73% (dry basis) of total mass; therefore, hull moisture contents were 22.2 and 24.6%, repsectively. The above kernel and hull moisture contents represent those that normally occur with harvest following windrow curing, in which case the hull moisture content is below that in equilibrium with the kernel moisture content. Simulations were run for airflow rates of 5, 10, and 15 m^3/min/m^3 for the two contents studied.

Curing time was defined as the time required to cure peanuts from the initial moisture content to an average kernel moisture content of 10%. Fuel use was calculated using the procedure described in Baker *et al.* (1991).

Table 1. Description of Heater Control Methods Tested.

1. **Conventional control (CC) - A temperature rise of 8.5C is added to ambient air temperature with a maximum temperature limit of 35C.**
2. **Humidistat control (HC) - If ambient relative humidity exceeds 70%, a temperature rise of 8.5C is added to ambient air temperature with a maximum temperature limit of 35C. If ambient air relative humidity is below 70%, no heat is added.**
3. **Drying rate control (DRC) - A variable temperature rise is added to ambient air in order to raise the drying air temperature to 1C below the maximum curing air temperature recommended by Young et al. (1982). This maximum curing air temperature is a function of humidity ratio (W) as follows:**

$0 < W \leq 0.008$ $T_{max} = 1111\ W + 15$

$0.008 < W \leq 0.012$ $T_{max} = 763.9\ W + 17.78$

$0.012 < W \leq 0.02675$ $T_{max} = 546.2\ W + 20.39$

$W > 0.02675$ $T_{max} = 35$

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[3] Data were analyzed using standard analysis of variance and Duncan's multiple range testing methods with a type I error probability level of 5% (α=0.05).

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The amount of LP-gas needed to cure a trailer of peanuts was determined assuming a trailer net weight of 3560 kg at 10% moisture content, equivalent to a 4.3 x 2.3 m trailer filled to an average depth of 1.5 m.

Air conditions in the top layer of peanuts were used to determine mold risk. Conditions listed by Smith and Davidson (1982) as an extreme danger zone for *Aspergillus flavus* growth (air relative humidity > 85% and air dry bulb temperature > 25 C) were assigned twice the risk as those in the mild danger zone (air relative humidity > 80% and air dry bulb temperature > 12 C). For example, one hour of air conditions in the extreme danger zone added two units to the risk total, while one hour of air conditions in the mild zone added one unit. Total units of risk for each cure were summed. A mold risk index was defined for each heater control strategy at each airflow rate and initial moisture content studied and encompassed 34 different starting dates over five years for a total of 170 simulations. This index is the percent of total of 170 simulations in which the total units of risk were greater than 24. The level of 24 was selected so that the mold risk index would be less than 1 when initial moisture content is 25%, airflow rate is 10 $m^3/min/m^3$, and conventional heater control is used. These conditions are the current recommendations for peanut curing in Virginia, and mold growth while curing is not a problem if these recommendations are followed. The mold risk index was designed to be used as a tool for comparing the likelihood of mold growth with different heater control methods and is not intended to be used as a tool for predicting the amount of or presence of aflatoxin.

Laboratory Curing Tests

For each test, peanuts (cv. NC 6) were dug, allowed to cure in inverted windrows for four to six days, and them combined. The peanut pod moisture content ranged from 21 to 30% when combined. After combining, peanuts were placed in nine drying columns and cured with three different airflow rates using the three different heater control methods (Table 1). Each drying column was an insulated cylinder with an inside diameter of 34.4 cm. The column consisted of four sections, each holding a 30.5 cm depth of peanuts; therefore, the total depth of peanuts in each column was 1.22 m. Screen wire in the bottom of each section segregated the four sections of peanuts. Peanuts were cured in each of the columns until the average kernel moisture content was approximately 10%. In order to determine the stopping time for each of the drying columns, pod moisture content was estimated by removing the top section of each column (top 25% of the peanuts) and weighing it to determine moisture loss. The curing test was stopped when the top section pod moisture content (estimated by weight loss) was 10.5% for tests with airflow rates of 10 and 15 $m^3/min/m^3$ and when the top section pod moisture content was 11% for tests with an airflow rate of 5 $m^3/min/m^3$.

Three during columns were installed on each dryer. Airflow rates to each column were controlled by perforated plates, designed so that airflow rates would be 5, 10, and 15 $m^3/min/m^3$ through the three columns when filled with peanuts to a 1.22 m depth. The plates had been calibrated before the tests by measuring pressure drops vs. airflow rate. During the tests, the pressure drop was measured and airflow rate determined from the calibration equations. Adjustments were made to set airflow rate at the desired levels. Pressure drop across the plate was measured every six hours during the day and a damper on the fan inlet adjusted to maintain the set airflow rate.

To control air conditions for each dryer, a fan delivered ambient air through a moisture saturation column and a bank of heaters, then through the perforated plates into the individual drying columns Fig. 1). The moisture saturation column saturated the air and conditioned it to the desired dew point temperature. The electric heaters then raised the air temperature to the desired dry bulb temperature while holding the dew point temperature constant (Steele, 1968).

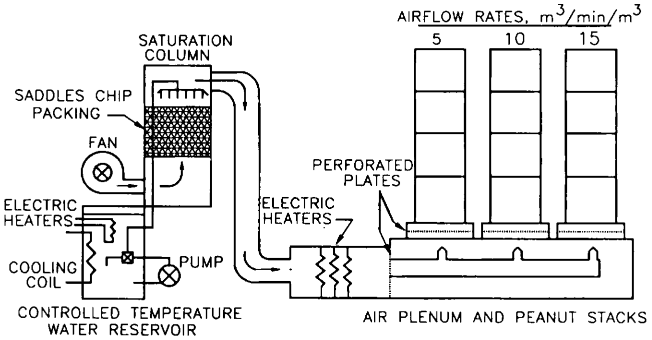

Fig. 1. Schematic drawing of the air conditioning and drying equipment used for each heater control method. Three such units were used for each test.

Air conditions programmed for the tests were actual weather conditions measured with the AEMS. Three periods of weather, judged as poor, average, and good drying conditions were chosen from data collected for the period September 25 through October 31 during the years from 1987 through 1989. Performance predicted by a bulk drying model (Colson and Young, 1990) was the criterion for determining which blocks of time had poor, average, and good drying conditions. Curing time, energy use, and mold risk were considered when selecting these time periods. Poor weather conditions began October 18, 1989; average conditions began September 26, 1989; and good conditions began October 15, 1988. The same weather conditions were programmed for each individual test. A test was defined as one cure with all three dryers running, each with a different heater control method. All three weather conditions were used in at least one test.

Initial conditions for each of the five curing tests run in 1990 and four tests in 1991 are given in Table 2. As shown, the percent loose-shelled kernels (LSK) and foreign material (FM) was quite low for the sample used for all the tests. Average values for farmers' stock peanuts at the first point of sale are typically about 3% for both LSK and FM (Davidson *et al.*, 1982).

Table 2. Initial Conditions for the Nine Laboratory Curing Tests. Peanut Cultivar was NC 6 for all Tests.

Test No.	Simulated Weather Conditions	Date Peanuts Dug	Date Peanuts Combined	Initial Moisture Content			Initial Peanut Temp. (C)	Percent Kernels (db)	LSK (%)	FM (%)
				Pod	Kernel	Hull				
90-1	Average	9/27	10/1	30.5	32.9	24.4	21	69	0.4	1.1
90-2	Poor	10/1	10/5	29.5	30.1	28.0	20	70	0.4	1.2
90-3	Good	10/5	10/9	24.5	25.3	22.5	25	71	0.4	0.6
90-4	Average	10/11	10/16	20.7	21.7	17.6	21	75	0.6	0.9
90-5	Good	10/17	10/22	27.0	27.9	23.8	22	76	0.9	1.1
91-1	Good	9/18	9/23	27.9	28.6	25.8	23	74	1.1	0.8
91-2	Poor	9/27	10/1	27.2	28.0	24.8	26	74	0.9	1.3
91-3	Average	10/2	10/8	30.0	31.1	26.7	21	74	0.9	0.8
91-4	Good	10/9	10/14	25.9	26.5	24.1	20	74	1.0	1.2

After selecting three weather periods, the dry bulb and dew point temperatures were averaged over a one hour period and frequency signals were recorded on audio cassette tapes which controlled the temperature set points of the saturation column and the electric heaters. Steele and Burkholder (1976) describe the temperature control equipment and procedure.

Eighteen 200 g samples (two from each drying column) were randomly obtained from the test lot before curing in order to determine the initial moisture content and the percentage of kernels in the peanut pods. Kernel and hull moisture contents were determined using the oven drying method described in ASAE standard S410.1 (ASAE, 1990). Percent kernels was calculated using oven-dried weights.

While the tests were being conducted, temperature of the saturated air (exiting the saturation column) and temperature of the heated air entering each column were measured using copper/constantan thermocouples. A data logger (Campbell Scientific model CR21X) was used to average the thermocouple readings over 15-minute intervals and to record the averages.

After curing was complete in a drying column, the four sections of the drying column were removed from the air plenum and replaced with a damper. The damper was adjusted to maintain airflow rates of the remaining drying columns at the set levels. From each drying column, four 200 g samples were obtained for moisture content determination. One of these was from the bottom one-tenth of the column and one from the top one-tenth of the column. The other two samples were obtained at random from the remainder of the drying column (middle eight-tenths). Additionally, two 1200 g samples were obtained for peanut quality determination using standard grading procedures for farmers' stock peanuts. One of these samples was from the bottom one-tenth of the column and the other was from the middle eight-tenths of the column. Another 1200 g sample was obtained from the bottom one-tenth of the drying column and was analyzed for organic volatile concentration using the procedure developed by Dickens *et al.* (1987).

Extra large kernels (ELK) from 500 g of graded peanuts collected from the bottom one-tenth of the drying column were retained and used to evaluate skin slippage in five of the tests. Two 100 g subsamples were tested from each of these samples. To test for skin slippage, individual kernels with a moisture content of about 6.7% and at a temperature of about 15 C were placed between the thumb and index finger and a moderate pressure applied. The percentage of kernels, by weight, on which the seed coat detached from the cotyledons was recorded as skin slippage.

Results and Discussion

Simulation Studies

During the good weather period, the curing air temperatures produced by the three heater control methods were quite different. Curing air temperatures for conventional control (CC) varied significantly throughout each simulation because of the diurnal swing typical of the Virginia peanut growing region in late September and October (Fig. 2). Use of humidistat control (HC) reduced the variation by lowering curing air temperature during the daytime hours when ambient air was warmer. Use of drying rate control (DRC) resulted in a nearly constant curing air temperature of about 22 C. With good drying weather, the curing temperature for DRC was sometimes below ambient temperature. In practical applications this would require refrigeration equipment, which could not be justified economically. Using ambient air at these times rather than DRC would probably not significantly affect the results.

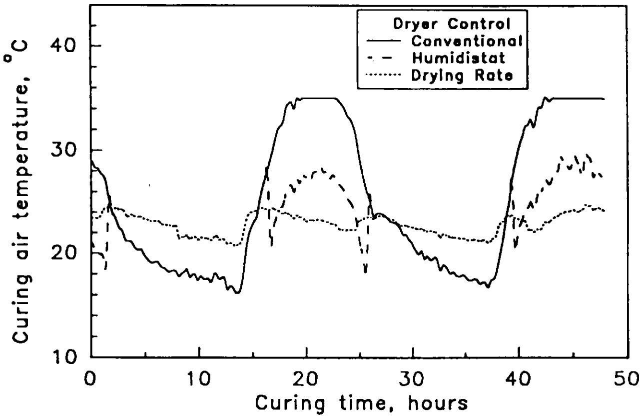

Fig. 2. Curing air temperatures for the heater control methods for a period of time when ambient weather conditions were good for drying.

As a result of the curing air temperature variation, drying rates for CC were more variable than those for HC and DRC, resulting in higher drying rates for CC during certain parts of the curing period (Fig. 3). DRC eliminated the diurnal fluctuation and produced a drying rate curve with approximately constant slope. In theory, skin slippage in peanut kernels is influenced by drying rate. Differences in drying rate show the possibility of higher skin slippage for CC than for HC or DRC.

Predicted curing times were nearly the same with CC and DRC, but predicted curing time for HC averaged 17% longer than for CC (Table 3). Percent differences in predicted curing time were consistent over the range of airflow rates and initial moisture contents studied. Maximum predicted curing times were up to 20% longer for HC than for CC or DRC. Thus DRC satisfies the objective of an alternate control method that does not increase curing time, while HC increases curing time significantly.

Estimated fuel use averaged about 3% more for DRC than for CC, while fuel use decreased about 14% for HC (Table 3). Thus, DRC nearly satisfies the objective of an alternate control method that does not increase fuel use. HC gives a producer the option of reducing fuel cost at the expense of an increase in curing time. Percent differences in estimated fuel use were consistent over the range of airflow rates and initial moisture contents studied. Airflow rate effects on curing time and fuel use are discussed more extensively in Baker *et al.* (1991).

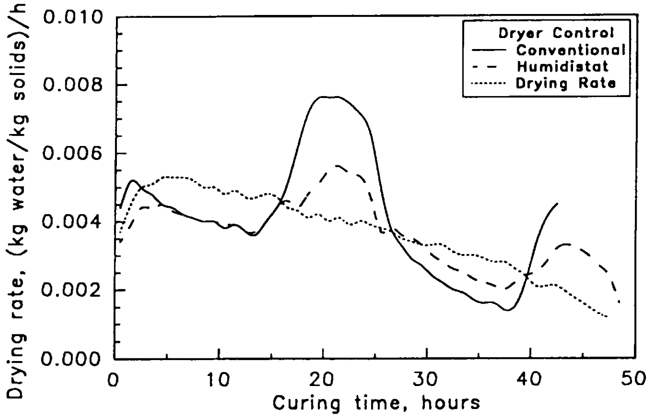

Fig. 3. Drying rate of the bottom layer of peanuts for the three heater control methods during good drying weather.

Predicted mold risk and the predicted range in final moisture content from the bottom to the top of a trailer varied little among the three heater control methods (Table 3). Thus, neither DRC nor HC increases the risk of fungal invasion while curing or during subsequent storage.

Laboratory Curing Tests

Initial pod moisture content across the nine curing tests conducted during 1990 and 1991 ranged from 20.7 to 30.5%, which represents the range of harvested moisture content typical of peanuts in southeastern Virginia. Temperature of the peanuts ranged from 20 to 26 C. The percentage of LSK and FM in the test lots was relatively low when compared to average values for farmers' stock peanuts.

Curing time was significantly dependent[3] upon heater control method. Curing times were nearly the same with conventional control (CC) and drying rate control (DRC), but curing time for humidistat control (HC) averaged 11 h (16%) longer than for CC (Table 4). Experimental heater control method effects on curing time were the same as those predicted by the bulk curing model.

In all cases, the simulation predicted lower curing times than those determined experimentally. Percent deviation for curing time predicted by the simulation from that determined experimentally ranged from -4 to -21, and averaged -13. Percent deviation was affected by airflow rate. Tests with lower airflow rates had better agreement between predicted and observed curing times. Tests with an airflow rate of 5 $m^3/min/m^3$ had percent deviations which average -9, while tests with airflow rates of 10 and 15 $m^3/min/m^3$ had percent deviations which averaged -15. The heater control method used did not affect percent deviation.

The final moisture content difference between samples from the top and bottom of the dryer was not dependent upon heater control method (Table 4). The observed difference was slightly less than that predicted by the bulk curing model.

Visible mold growth was observed in the top layers of drying columns for all tests in which the mold risk calculated by the simulation model was greater than 36 and for none of

Table 3. Simulated Curing Results for the Three Heater Control Methods.

Airflow Rate	Avg. Curing Time (h)			Curing Time Range (h)			Fuel Use, (Liters LP-Gas/Trailer)			Mold Risk Index (%)			Final M.C. Range, Bottom to Top (%)		
($m^3/min/m^3$)	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC
25% Initial Moisture Content															
5	62	72	61	56-73	63-88	53-73	136	116	141	53	64	53	7.3-13.4	7.5-13.3	7.2-13.5
10	47	55	47	43-60	47-67	43-62	205	178	212	<1	<1	<1	8.2-12.0	8.5-11.7	8.3-11.8
15	43	50	43	40-54	42-62	38-56	286	243	295	<1	<1	<1	8.7-11.3	8.9-11.2	8.8-11.2
30% initial Moisture Content															
5	79	93	78	71-93	81-111	70-96	174	150	181	68	79	76	6.7-15.1	7.1-14.8	6.6-15.0
10	61	71	59	54-72	60-86	53-77	267	226	275	4	6	5	7.9-12.4	8.1-12.3	7.9-12.5
15	54	63	53	48-68	53-76	47-68	356	309	368	<1	<1	<1	8.5-11.7	8.6-11.5	8.5-11.7

the tests in which the mold risk was 36 or less. This included tests with initial moisture contents above 25%, airflow rates of 5 and 10 $m^3/min/m^3$ and poor drying weather. Heater control method did not appear to affect the presence or amount of visibly moldy pods. These results suggest that a value of 36 rather than 24 should be used to determine the mold risk index value; however, these experiments were not designed to specifically test the mold risk index calculation and further testing is needed before a recommendation could be made for changing the value used in the mold risk index calculation.

The amount of splits in the grade samples were relatively insignificant in all cases when compared to the 4% value that is allowed before a price discount is applied to farmers' stock peanuts. The overall average amount of splits in the nine tests was 0.9%, and the maximum observed value was 1.9% (Table 4). The percent splits was slightly higher for the last two tests of each harvest season, probably due to increased maturity of the peanuts (Table 4). Based upon splits as a quality factor, the conventional heater control method is acceptable.

Volatile organic matter (VOM) concentrations in the headspace of comminuted peanuts were low. Low values indicate good roasted flavor potential. Values for all heater control methods were nearly the same. All samples tested had values below 8 mg ethanol/kg air, which is a level which has been determined to have acceptable flavor. As with percent splits, the VOM concentration data did not differentiate between the three heater control methods.

Heater control method significantly affected the percentage of subjectively determined skin slips. CC yielded the most skin slips, an average of 60% for ELK (Table 4). Percentages for HC and DRC averaged 26 and 38% lower than CC, respectively. Differences between HC and DRC were not significant. In the 1991 tests with good drying weather, DRC resulted in the lowest values for skin slippage. In these tests, values for DRC averaged 47% lower than those for CC. Skin slippage percentages for the 1991 tests were much greater than those for corresponding 1990 tests. This increase in skin slippage may be due to differences in conditions which occurred during the kernel development portion of the growing season or during windrow curing.

The simulation and experimental results for DRC appear promising as they satisfy the objective of an alternate heater control method which results in higher quality peanuts without increasing curing time or fuel use. Shellers want peanuts with low skin slip propensity because they produce less split kernels when shelled. Instrumentation to incorporate the DRC method with the LP-gas heaters used on peanut dryers is not currently available and would need to be developed should the method prove feasible.

Peanuts are not currently being tested for skin slippage

Table 4. Results from Laboratory Curing Studies for the Three Heater Control Methods.

	Curing Time (h)			Final M.C. Spread (% pt.)			Percent Splits			Headspace VOM Concentration			ELK Skin Slips (%)		
Test No.	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC	CC	HC	DRC
90-1	78	89	73	3.0	4.4	3.6	0.4	0.3	0.3	NR*	NR	NR	NR	NR	NR
90-2	93	113	92	1.9	3.2	3.4	0.3	0.5	0.7	NR	NR	NR	NR	NR	NR
90-3	65	74	61	3.5	2.5	2.0	1.1	0.7	0.3	4.8	3.8	3.9	NR	NR	NR
90-4	57	65	57	2.1	2.1	1.3	1.0	1.1	1.0	NR	NR	NR	NR	NR	NR
90-5	58	69	61	2.7	2.6	2.5	1.6	1.3	1.3	5.3	3.6	3.2	46	18	33
91-1	59	71	62	4.0	4.3	3.6	0.8	0.9	0.6	1.7	1.7	1.9	64	47	30
91-2	74	83	69	3.1	2.4	3.3	0.9	0.6	0.8	3.1	5.1	3.9	55	45	41
91-3	75	84	78	3.9	3.9	3.2	1.2	1.2	1.3	4.3	2.5	3.2	70	56	45
91-4	57	68	59	3.4	3.2	2.1	1.9	1.3	1.1	2.8	3.2	4.1	67	58	39
Test Average	68	79	68	3.1	3.2	2.8	1.0	0.9	0.8	3.7	3.3	3.4	60	45	38

* NR - Not recorded

when they are marketed, since the testing method is subjective and very time-consuming. There is a need for a mechanized, objective method for measuring skin slippage. Such a method would allow peanut buyers to compensate those growers who choose to produce peanuts with lower skin slippage.

Summary and Conclusions

Bulk curing simulation studies and nine laboratory curing tests were conducted to evaluate a proposed heater control method for peanut dryers. The new method, termed drying rate control (DRC) was compared with conventional control (CC) and humidistat control (HC) using airflow rates of 5,10, and 15 $m^3/min/m^3$ at initial moisture contents ranging from 25 to 30%. Curing time to 10% average kernel moisture content, estimated fuel use, mold risk and mold risk index values, final moisture content difference between bottom and top, percent splits in a grade sample, VOM concentration in the headspace of comminuted peanuts, and percentage of skin slips were determined. The following conclusions were drawn:

- Curing time averaged 16% longer for HC than for CC and DRC. Curing times for the latter two heater control methods were nearly the same.
- Estimated fuel use averaged 14% less for HC than for CC. Fuel use was estimated to be only 3% more for DRC than for CC.
- Differences in mold risk, final moisture content spread, percent splits when graded, and volatile organic matter concentration in the headspace of comminuted peanuts were insignificant among the three heater control methods.
- Percent skin slips were about 30% less with DRC and HC than with CC.
- The need exists for a mechanized method to objectively and quickly measure skin slippage.

In summary, DRC resulted in less skin slippage than CC with similar curing time and similar fuel cost. HC resulted in less skin slippage than CC with lower fuel cost, but increased curing time. The three heater control methods had negligible differences in mold risk, flavor potential, and grade factors.

Acknowledgments

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