Comparison of Peanut Dryer Control Strategies[1]

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ABSTRACT

Peanuts were mechanically cured from field moisture contents ranging from 11.5 to 32.8% wet basis to levels acceptable for marketing (<10.5%) using two dryer control strategies. The first control algorithm consisted of a constant thermostat setting of 39 C, while the second required manual thermostat control on an hourly basis such that the minimum plenum relative humidity was between 40 and 60% and the maximum plenum temperature was less than 39 C. The average drying rate using the variable thermostat set point (0.3%/hr) was half that obtained with the constant set point (0.6%/hr). Average curing time for the variable thermostat setting was 56% longer than for the peanuts cured using the constant thermostat. Fuel consumption was reduced by approximately 30% using the variable set point. Kernel size distributions and milling quality indicated by bald kernels were significantly better ($P \leq 0.1$) for peanuts cured using the variable thermostat control. Increasing available dryer capacity by 40% would allow the buying point manager to handle the same amount of peanuts during the same harvest interval. Economic analysis showed that the annual capital cost for additional drying equipment could not be offset by energy savings alone. Based on increased shelled product value and energy savings, shellers could realize an increase in net revenue of approximately $14/1000 kg of farmers stock peanuts by using a variable thermostat set point.

Key Words: Peanut curing, quality, controls, costs, value.

Peanuts are mechanically cured from moisture contents of approximately 20% wet basis (w.b.) to levels less than 10.5% for marketing. High drying air temperature and low relative humidity result in excessive drying rates and overdrying. Plenum temperatures should not exceed 35 C to prevent offensive off-flavors, split kernels, and skin slippage during shelling (Beasley and Dickens, 1963; Woodward and Hutchinson, 1972). The relative humidity of the drying air entering the peanuts should be no less than 50 to 55% according to university extension service recommendations (Samples, 1982; Talbot, 1983). A temperature rise of 8-10 C above ambient conditions has been recommended as a practical method, without humidity controls, to prevent excessive drying rates (Samples, 1982; Young *et al.*, 1982; Talbot, 1983). According to the psychrometric chart, a 10 C rise above ambient temperature will reduce the relative humidity of the drying air to approximately one-half that of ambient air. Results of simulation studies for bulk curing of peanuts indicated that a maximum rise of approximately 8 C was an optimum compromise to preserve peanut quality and conserve energy (Troeger, 1982).

Blankenship and Chew (1978) showed that intermittent fan operation during peanut curing reduced electricity and fuel consumption. Steele (1982) incorporated ideas of intermittent fan operation and variable thermostat set points to reduce the curing energy consumption for Virginia weather conditions. Steele (1982) successfully reduced electrical energy use by 39% and propane (LP) consumption by 49% while increasing curing time by 10%. Baker *et al.* (1993) compared a drying rate control (DRC) with humidity control (HC) and conventional control (CC). Average curing times were the same for CC and DRC, but averaged 17% longer with HC. Fuel costs were nearly the same for CC and DRC, but were 14% less for HC. Percentage skin slippage in the extra large kernels was measured with a subjective test, and averaged approximately 30% less with DRC and HC as compared to CC. DRC resulted in better peanut quality than CC with similar curing time and fuel costs.

The time required to reduce the moisture content of peanuts to an acceptable level for marketing plays an important role in the operator's decision to follow recommended curing practices. The approach of unfavorable weather or the lack of sufficient drying equipment may cause the dryer operator to increase the drying air temperature to free dryer space and/or dryer bins. Field surveys have shown that operating temperatures of commercial drying stations often exceed those recommended. Excessive curing temperatures sacrifice quality and economy. Other potential problems occur due to overdrying the peanuts. Butts (1995) demonstrated that curing peanuts to 7% w.b. instead of 10% increased variable curing costs by approximately $16/1000 kg of farmers stock peanuts marketed and drying time by 11 hr/1000 kg of farmers stock peanuts. In Georgia, many of the peanuts are cured at commercial stations where the number of trailers cured simultaneously can exceed 60 during the peak of peanut harvest. Monitoring a large number of trailers increases the probability of overdrying. Managers are reluctant to invest significant capital in dryer controls. Therefore, a simple algorithm to manually set thermostats based on ambient conditions is needed to consistently follow recommended drying practices.

The overall objective of this research was to determine the economic benefits of utilizing an algorithm to manually vary the thermostat set point according to the ambient temperature and humidity. Specific objectives were (a) to compare the drying rates, fuel requirements, and farmers stock grades for peanuts cured with constant and variable thermostat set points and (b) to compare the shelling quality of peanuts cured using constant and variable thermostat set points.

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

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Materials and Methods

Runner-type peanuts grown using conventional cultural practices in Georgia were dug and allowed to cure in the windrow. After a minimum of 2 d in the windrow, the peanuts were harvested and loaded into conventional drying wagons measuring 2.4 m wide, 4.3 m long, and 1.3 m deep. Four wagons were filled with peanuts from the same field to minimize variability due to growing conditions and maturity. As the wagons were loaded, the peanuts were leveled following each dump of the combine. Two 4.5-kg samples were collected in mesh bags while filling each wagon. The samples were collected in mesh bags and buried approximately 25 cm below the upper surface of the peanuts. The wagons were transported to a local peanut buying point for curing.

The peanut wagons were weighed at the buying point using platform scales certified by the state of Georgia for commercial operation. The wagons were moved to the drying shed where each was connected to a single-wagon LP-fired dryer (Peerless Model 153J). The thermostat was permanently mounted in the flexible duct transition connected to the drying wagon plenum. The fans (5.2 kW) delivered approximately 300 m^3/min at 5 kPa static pressure. Each of the dryers had its own LP supply tank. LP consumption during the tests was determined by weighing each tank immediately prior to starting the dryer and again after curing was complete.

After connecting the dryers to the wagons, a sample of peanut pods was obtained from the trailer by vertically probing the peanuts with a 1.8-m grain probe at three to five locations. This procedure provided a 500-700-g sample for moisture determination. The peanut pods were shelled using a flat vibrating screen sheller of the type approved by the Federal-State Inspection Service (USDA, 1991). The moisture content of a 200-250-g subsample of kernels was determined using an electronic moisture meter (Dickey-John GAC II). After the kernels were removed from the electronic moisture meter, they were placed in a polyethylene bag, labeled, and sealed. A 50-g subsample of the hulls was obtained and place in a separate polyethylene bag, labeled, and sealed. The moisture content of the hulls and kernels was determined using the oven method described in ASAE Standard S410.1 (ASAE, 1994).

Plenum temperatures were measured using copper-constantan (ANSI Type T) thermocouples, while ambient temperature and relative humidity was measured using a Campbell Scientific CS-207 sensor. Temperature and humidity data were monitored at a 10-min interval using a Campbell Scientific CR7X datalogger and hourly averages recorded on magnetic tape.

Peanuts were cured using two algorithms to determine thermostat set points. The first algorithm had a constant set point of 39 C, the thermostat setting often observed in commercial practice. The second algorithm required that the operator set the thermostat hourly such that the temperature of the air entering the peanuts was ≤39 C and the relative humidity was between 40 and 60%. The operator used a sling psychrometer to measure the ambient wet and dry bulb temperatures, then determined the set point according to the information shown in Table 1. This manual method of controlling the temperature was chosen to avoid the cost of automated controls and to emulate a likely method implemented at a buying point. All thermostats were calibrated during each run using a stem thermometer located in the rear panel of the drying wagon plenum.

Table 1. Thermostat point (C) based on the ambient dry (T_{db}) and wet (T_{wb}) bulb temperatures.

	Wet bulb depression (T_{db} - T_{wb}, C)							
T_{db}	0	1	2	3	4	5	6	7
	Thermostat set point (C)							
15	25.0	24.5	22.5	21.0	18.5	16.0	15.0	15.0
20	30.0	30.0	28.5	27.0	24.7	23.0	20.7	20.0
25	35.0	35.0	34.0	32.5	31.0	29.2	27.2	25.0
30	39.0	39.0	39.0	38.5	37.0	35.3	33.7	32.0
35	39.0	39.0	39.0	39.0	39.0	39.0	39.0	38.0
40	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0

Two of the four loads of peanuts were cured using the constant thermostat set point (CSP) and two cured using the variable thermostat set point (VSP). Kernel moisture content was monitored throughout the curing process using the electronic moisture meter. When the average kernel moisture content was below 10.5%, the dryer was turned off and disconnected from the wagon. Kernels and hulls from the final moisture sample were retained for oven determination of the final moisture contents as previously described for the initial moisture content sample. The two sample bags in each wagon were uncovered and placed on top of the peanuts in the wagon. The wagons were sampled and graded as part of the normal commercial operation by the Federal-State Inspection Service. After the peanuts were graded, the bagged samples were removed from the wagon and stored for shelling quality evaluations.

A total of 28 wagons were cured during the time period 29 Sept. to 19 Oct. 1988. Peanut samples were returned to the National Peanut Research Laboratory and stored in the pilot shelling plant on pallets until shelling was accomplished. A total of 28 samples from wagons cured using the CSP and 26 samples from wagons cured using the VSP were collected and analyzed. All peanut samples were shelled during March 1989. Shelled kernels were separated into the commercial market grade sizes for runner type peanuts using flat vibratory screens on the Model 4 sheller (McIntosh *et al.*, 1971; Davidson *et al.*, 1976). The edible grade peanuts (jumbo, medium, and number one sized kernels) were subsampled to determine the proportion of bald-face kernels. The results of the shelling analyses were evaluated for significant differences using the LSMEANS option of the General Linear Model procedure (SAS, 1985).

Results and Discussion

Initial kernel moisture content (oven method) of the 28 loads averaged 19.4% and ranged from 11.5 to 32.8% (Table 2). The variation of the initial moisture content of four wagons from a single field varied as much as 5% w.b. The final kernel moisture content (oven method) ranged from 8.6 to 10.7% and averaged 9.9% for all loads cured during the test. After the peanut samples were stored for approximately 5 mo, the kernel moisture content (oven) averaged 6.4% (0.3% S.D.) at the time of shelling.

Air conditions were generally more favorable for curing high quality peanuts (i.e., slower moisture removal rates, less energy and improved milling quality) using the VSP. The average plenum temperature for all curing tests was 33 C using the CSP, and ranged from 23 to 42 C. The VSP plenum temperature averaged 26 C with a maximum of 37 C and a minimum of 21 C. This was an average 7 C cooler than the plenum temperature achieved using the CSP. The average rise above ambient was 11 and 4 C for the CSP and VSP, respectively. At similar airflow rates, the consumption rate of fossil fuels for the VSP should be approximately one-half that using the CSP. However, total fuel consumption could be higher due to the longer time required to cure the peanuts. Data showed that the total consumption of propane using the VSP was 33.6 L/1000 kg of marketed peanuts and approximately one-half that using the CSP (64.5 L/1000 kg). Using the VSP, LP consumption ranged from 0.5 to 88.6 L/1000 kg, whereas CSP ranged from 13.8 to 152.8 L/1000 kg depending primarily upon the amount of moisture to be removed from the peanuts. The VSP utilized mostly ambient or near ambient drying air during the additional time required to cure the peanuts. On the basis of moisture removal, the VSP required only 70% of the fuel required by the CSP. The fuel consumption required on the moisture removal basis was 24.5 L/% with the CSP compared to 16.7 L/% with the VSP.

The average relative humidity of the drying air for the CSP and VSP strategies was 31 and 42%, respectively. The minimum plenum relative humidity during the test period was 12% for the CSP and 28% using the VSP. The higher relative humidity occurred using the VSP because no heat was added to the drying air unless the ambient relative humidity was greater than 50%.

The peanuts cured using the CSP required an average of 18 hr to dry (Table 2) at an average rate of 0.6%/hr. Peanuts cured with the VSP dried at an average rate of 0.3 %/hr and increased drying time to an average of 29 hr, or 58% longer than the CSP.

Farmers stock grades were not statistically different for the two dryer control schemes (Table 3). However, the distribution of kernels in commercial shelled stock categories and bald kernels (Table 4) was significantly different at the P ≤ 0.1 level. The percentages of jumbo- and medium-sized kernels were higher (13.8 and 33.5%, respectively) for the VSP as compared to the CSP (12.3 and 32.7%). Percentage number one-sized kernels averaged 9.1 and 9.6%, respectively, for the constant and variable set point controls. The percentage oil stock was 1.1% lower in the VSP-cured peanuts compared to the CSP-cured peanuts. These trends indicate that the peanut kernel size distribution shifts from larger to smaller as the harshness of the curing regime increases. The percentage of bald kernels in all whole kernel size categories cured using the VSP was 50% that observed in CSP-cured peanuts. During handling, whole peanut kernels with loose or missing skins will break and split, thus reducing the total amount of whole kernels available for sale at the higher price for whole kernels. Data in Table 4 show the total percentage of whole kernels, bald kernels, and the net result if all bald kernels were split for the two curing treatments.

Table 2. Summary of tests curing peanuts using constant and variable thermostat set points.

	Constant set point			Variable set point		
	Mean	Max.	Min.	Mean	Max.	Min.
Initial moisture[a] (%)	19.2	30.6	12.3	19.6	32.8	11.5
Final moisture[a] (%)	9.7	10.7	8.6	10.1	10.6	9.7
Plenum temperature (C)	33.4	42.0	22.6	26.4	36.5	20.6
Plenum humidity (%)	31	56	13	42	67	28
Temperature rise (C)	10.9	21.5	4.4	4.3	12.2	0.4
Drying time (hr)	18.2	25.3	9.3	28.7	50.4	3.1
Propane used (L/1000 kg)	64.5	152.8	13.8	33.6	88.6	0.5

[a] Moisture contents shown were determined using the oven method (ASAE Standard S410.1).

Table 3. Farmers stock grades for peanuts cured using constant and variable thermostat set points (no significant differences at P=0.1).

Grade factor	Constant		Variable	
	Mean	S.D.	Mean	S.D.
	– – – – % – – – –		– – – – % – – – –	
Foreign material	4.93	1.86	5.26	2.78
Loose shelled kernels	4.00	1.15	5.30	2.20
Sound mature kernels	66.86	4.16	66.85	4.37
Sound split kernels	3.14	1.33	2.85	0.95
Other kernels	7.50	3.00	7.63	3.19

A peanut buying point would have to purchase more peanut drying equipment and construct a drying shed to house the dryers to maintain seasonal capacity using the VSP dryer control strategy. The cost of the dryers and shed would have to be offset by reduced fuel costs, electrical costs, and increased product value. The economic feasibility (savings versus costs) depends on the total amount of peanuts handled by the buying point, the cost of fuel and electricity, cost of the farmers stock peanuts, and the price paid for the final shelled product.

***Capital Investment**:* Using the CSP dryer control, a typical peanut buying point can cure approximately 1000 loads of peanuts in 30 d without any wet peanuts waiting for dryer space using 50 drying units. To handle the same volume in the same time period, using the VSP, a peanut

Table 4. Comparison of kernel size distributions[a] and shelling quality of peanuts cured using constant and variable thermostat set points.

Kernel size		Control Constant	 Variable	P ≤ |T| Constant = Variable
		----- % -----		
Jumbo	Total[b]	12.30	13.80	0.010
	Bald[c]	0.20	0.10	0.126
	Net[d]	12.10	13.70	0.009
Medium	Total[b]	32.70	33.50	0.088
	Bald[c]	0.50	0.20	0.065
	Net[d]	32.20	33.30	0.045
No. 1	Total[b]	9.60	9.10	0.168
	Bald[c]	0.10	0.05	0.099
	Net[d]	9.40	9.00	0.221
Splits	Total[b]	10.60	10.10	0.366
	Bald[e]	0.80	0.40	0.076
	Net[f]	11.40	10.40	0.227
Oil stock[g]		8.60	7.50	0.050
Hulls		23.00	22.70	0.230

[a] Kernel size distribution expressed as percent of net weight.

[b] Total whole kernels consist of all kernels riding prescribed screen.

[c] Bald whole kernels consist of all kernels with 25% or more of skin missing.

[d] Net whole kernels is total whole kernels minus bald whole kernels.

[e] Bald splits is the sum of all bald kernels from jumbo, medium, and number 1 sizes.

[f] Net splits is total splits plus all bald kernels.

[g] Oil stock consist of kernels falling through 6.4 by 19.1 mm (16/64 by 3/4 inch) slotted screen plus loose shelled kernels and damaged kernels.

buying point would have to increase the number of dryers to 70. This increase most likely would be accomplished by purchasing 10 dual trailer drying units at a cost of approximately $2800 per dryer. Assuming the average life of 20 yr for a dual trailer dryer with no salvage value at the end of its useful life and a 9% annual interest rate, the annual fixed cost would be $340.48 per dryer. The buying point operator would increase annual maintenance costs by approximately $75 per dryer for a total annual cost of $415.48 per dryer. This translates to $4155 per year for all 10 drying units. Assuming the 1000 loads averages 3500 kg each, using the VSP control costs an additional $1.19/1000 kg for new dryers (Table 5).

Many commercial buying points own two or three peanut drying wagons for each dryer slot. This usually provides more than enough drying wagons, so that no additional peanut drying wagons are needed. However, other buying points may have to purchase additional wagons to accomodate the increased number of dryers. Assuming that the buyer will purchase two drying wagons for each of the 20 new peanut dryer spaces at a cost of $2500 each, then the total fixed cost for new wagons is $100 thousand. The annual fixed cost for the wagons amortized over 15 yr and 1000 loads of peanuts at 9% interest rate is $3.63/1000 kg (Table 5).

Table 5. Summary of annual costs and benefits of using a constant (CSP) and variable (VSP) set point peanut dryer control per 1000 kg of farmers stock peanuts.

	CSP	VSP	Savings (CSP - VSP)
	$	$	$
Capital Costs			
Wagons	0.00	3.63	-3.63
Dryers	0.00	1.19	-1.19
Shed	0.00	2.08	-2.08
Subtotal	0.00	6.90	-6.90
Variable Costs			
Fuel	9.35	4.87	4.48
Electricity	1.34	2.11	-0.77
Subtotal	10.69	6.98	3.71
Shelled peanut value	937.37	955.09	17.72
Total Savings			14.53

A drying shed including electrical and fuel lines would have to be constructed to house the 10 additional dryers (20 drying bays) at a cost of approximately $72,000. Assuming the useful life of the shed is 30 yr with no salvage value, and an interest rate of 9%, the annual fixed cost of the shed would be $7272/yr. Amortizing the annual cost over the peanuts cured each year results in a cost of $2.08/1000 kg. The total capital cost for equipment including dryers, wagons, and shed of implementing the VSP is $6.90/1000 kg of clean, dry peanuts marketed.

Operating Costs: The variable costs for a peanut curing facility include labor, heat energy, and electrical energy. Because the peanuts are curing at a slower rate, the additional 10 dryers can be operated with no additional labor; therefore, there are no additional labor costs. In the Southeastern U.S., LP is the most common fuel used to heat the air during curing. Other regions of the U.S., specifically the Southwestern U.S., use predominantly natural gas. A propane cost of $0.15/L was used. The CSP consumed an average 64.5 L/1000 kg of peanuts and cost $9.35/1000 kg as compared to 33.6 L/1000 kg, costing $4.87/1000 kg, using the VSP. Difference in electrical costs would be due to the difference in drying time and the additional 10 motors connected resulting in increased demand charges. Assuming that each dual unit is equipped with a 5.2-kW electric motor, the CSP would require approximately 13.57 kWh/1000 kg as compared to 21.40 kWh/1000 kg using the VSP. Accounting for demand charges and the progressive electrical fee schedules, electricity costs of approximately $0.099/kWh would result in electrical costs of $1.34 and $2.11/1000 kg for the CSP and VSP, respectively. The total variable costs for curing peanuts using the CSP is $10.69/1000 kg as compared to $6.99/1000 kg using the VSP (Table 5).

Peanut Value: Because there was no significant difference in the initial farmers stock grade, no difference in the price that the buying point would pay for the peanuts would be realized. However, the differences in the kernel size distribution due to VSP increased the value of the product sold by the sheller. Using the 8-yr average price for the various shelled stock categories (Table 6), the value of the shelled kernels cured using the CSP was $937.37/1000 kg while those cured using the VSP had a shelled stock value of $955.09/1000 kg (Table 6). The increased shelled stock value of $17.72/1000 kg resulted from the VSP controls.

Table 6. Shelling outturns and value of shelled peanuts for cured using constant set point and variable set point dryer controls.

Kernel size	Price	Shelling outturn[a]		Shelled value	
		Constant	Variable	Constant	Variable
	$/kg	-- kg/1000 kg[b] --		-- $/1000 kg --	
Jumbo	1.43	121	137	173.03	195.91
Medium	1.41	322	333	454.02	469.53
No. 1	1.39	94	90	130.66	125.1
Splits	1.41	114	105	160.74	148.05
Oil Stock	0.22	86	75	18.92	16.5
Total		737	740	937.37	955.09

[a] Shelling outturns based on net percentages presented in Table 4.

[b] Shelling outturns presented as kg of shelled peanuts per 1000 kg of farmers stock peanuts.

The benefits of using a VSP control strategy include decreased consumption of heating fuel ($4.48/1000 kg) and increased shelled kernel value ($17.72/1000 kg) with a total value of $22.20/1000 kg of peanuts cured. Total costs incurred using the VSP include increased electrical costs (0.77/1000 kg) and capital costs ($6.90/1000 kg) are $7.67/1000 kg. If additional drying wagons are not needed, then the cost of purchasing and installing new equipment can be offset by savings in fuel giving economic incentive to the contract buying point to improve peanut curing procedures. If new wagons are necessary, a net benefit of $14.53/1000 kg can be realized using a VSP dryer control strategy by the sheller-owned buying point through reduced energy costs and improved milling quality.

Summary and Conclusions

Peanuts were cured during the 1988 crop year using two dryer control algorithms. A variable set point control attempted to maintain the relative humidity of the peanut curing air between 40 and 60% and not to exceed 39 C. A constant set point attempted to maintain a constant temperature of 39 C. Drying time using the VSP was 58% longer than that using the CSP; however, the number of drying units only had to be increased by 40% to maintain the seasonal capacity of the buying point. Reduction in propane consumption and improvements in the kernel size distribution offset the cost of additional dryer equipment and facilities plus increased electrical energy consumption. The peanut shelling industry could realize a 14 to $18/1000-kg increase in revenue by using a VSP curing control strategy.

Implementing the VSP using manual manipulation of the thermostats, as in this test, is not practical at a commercial peanut curing facility because of the lack of reliable seasonal labor. However, low cost process controllers are available to automatically sense the ambient temperature and humidity, determine the proper set point, then control each peanut dryer. These automated controllers also monitor and record actual curing conditions for each load of peanuts.

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