Aerating Farmer Stock Peanut Storage in the Southeastern U.S.

C. L. Butts, J. W. Dorner, S. L. Brown, F. H. Arthur

Abstract. *A two-year study was conducted to determine acceptable aeration strategies for farmer stock peanuts stored in conventional warehouses with and without headspace ventilation. Farmer stock peanuts were stored in 1/10th scale model warehouses with various aeration and ventilation treatments. Peanuts were loaded into each warehouse in the fall and stored for about 190 days. Peanuts stored with aeration generally cooled faster than those stored without aeration. Aflatoxin was detected in the initial samples from the 2002 crop, but aeration significantly reduced the further production of aflatoxin in storage. Aflatoxin contamination was not a factor in the 2003 storage season. Value change based on kernel size distribution was not significantly affected by aeration. An aeration rate of 0.31 m^3 min^{-1} t^{-1} was sufficient for proper aeration when used without headspace ventilation. The reduced aeration rate of 0.10 m^3 min^{-1} t^{-1} in conjunction with headspace ventilation cooled the center of the peanut mass sufficiently to reduce the risk of aflatoxin production in storage. Headspace ventilation with aeration reduced the temperature difference between the top and bottom layers of peanut during storage.*

Keywords. *Aeration, Peanut, Storage, Ventilation.*

Aeration is the practice of forcing air through a stored agricultural product to control the temperature and moisture of the bulk, and it is used extensively in storing small grains in circular bins with perforated floors. Cottonseed is typically stored in flat storage, similar to farmer stock peanuts, and is usually aerated. Air is distributed through flat storage using evenly spaced tunnels in the floor or temporary perforated ducts laid on top of the floor (Wilcut et al., 2004).

Farmer stock peanuts have been aerated with airflow rates of 0.1 m^3 min^{-1} m^{-3} of storage volume (Davidson et al., 1982) using removable duct laid on the floor. Aeration systems cooled the stored peanuts faster than headspace ventilation alone (Smith and Davidson, 1984), but the duct sustained considerable damage during the unloading process. For this reason, most aeration systems were abandoned in favor of headspace ventilation. Most farmer stock peanut warehouses ventilate the headspace, either mechanically or naturally, to control moisture and temperature (Smith et al., 1995). Research showed that approximately 50% of the value loss of peanuts stored in the southwestern U.S. was due to excessive moisture loss during storage (Butts and Smith, 1995). As peanut production in Texas moved from central Texas to the more arid high plains region, new storage facilities were constructed. In the mid-1990s, some storage facilities were constructed in west Texas to store farmer stock peanuts with in-floor aeration systems with the goal of reducing shrink during storage due to excessive moisture loss. The warehouses were aerated by pulling air down through the peanuts at a rate of 0.31 m^3 s^{-1} t^{-1} when the ambient relative humidity was between 60% and 80% (Blankenship et al., 2000). Moisture loss was less in two out of three years compared to the historical average in the southwest (Butts and Smith, 1995).

In the southeastern U.S., most of the peanuts are planted within the first two to three weeks of May (Culbreath et al., 2005) to reduce the impact of tomato spotted wilt virus (TSWV). Prior to the increased prevalence of TSWV, peanuts were planted from 10 April to 10 May and even into early June (Henning et al., 1982) depending on soil moisture and temperature. Approximately 80% of the runner peanuts planted in the southeast are of the Georgia Green cultivar. The narrow planting window coupled with the domination by a single cultivar significantly narrows the window of optimum harvest.

Harvest capacity has increased dramatically within the last ten years so that the peanut crop can be harvested as close to optimum maturity as possible. Fifteen to twenty years ago, peanuts would be delivered to a peanut buying facility over a period of 6 to 10 weeks. A farmer stock peanut warehouse located at the buying facility would be filled gradually over that period. However, a peanut buying facility may handle 90% of the surrounding peanut crop in as little as three weeks. This requires that peanuts be dried, graded, marketed, and placed in storage within 48 h of leaving the farmer's field. This short time is not sufficient for the moisture and temperature in a 5 to 20 t load of peanuts to equilibrate with the ambient air conditions. Therefore, when peanuts are placed in storage, this excess heat and moisture must be removed to prevent microbial growth and subsequent aflatoxin contamination during storage.

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The authors are **Christopher L. Butts, ASABE Member Engineer,** Agricultural Engineer, and **Joe W. Dorner,** Microbiologist, USDA-ARS National Peanut Research Laboratory, Dawson, Georgia; **Steve L. Brown,** Extension Entomologist, Cooperative Extension Service, University of Georgia, Tifton, Georgia; and **Franklin H. Arthur,** Entomologist, USDA-ARS Grain Marketing and Production Research Center, Manhattan, Kansas. **Corresponding author:** Christopher L. Butts, USDA-ARS National Peanut Research Laboratory, P.O. Box 509, Dawson, GA 39842; phone: 229-995-7431; fax: 229-995-7416; e-mail: cbutts@nprl.usda.gov.

At the time of farmer marketing, a sample from each load of peanuts is visually inspected for *Aspergillus flavus*, the primary producer of aflatoxin in peanuts. If *A. flavus* is observed in the sample, the peanuts are labeled Segregation III and the price is severely reduced. According to Lamb and Sternitzke (2001), Segregation III classification costs the grower segment of the industry an average of $2.5M annually. The sheller segment of the peanut industry lost approximately $22.7M annually between 1993 and 1996, when peanuts were purchased as Segregation I peanuts and required additional processing after chemical analysis revealed unacceptable levels of aflatoxin (Lamb and Sternitzke, 2001).

Commercial farmer stock peanut storage operators began installing aeration systems in new warehouses using the previously established rate of 0.31 $m^3\ s^{-1}\ t^{-1}$ with three air delivery tunnels embedded in the warehouse floor. However, the question remained as to whether or not a single tunnel down the middle of the warehouse, directly under the roof ridge and supplying air at a rate of 0.10 $m^3\ s^{-1}\ t^{-1}$, was adequate. Based on experience in aerating other fall crops (Loewer et al., 1994), concerns in aerating farmer stock peanuts include controlling moisture and temperature, airflow distribution, and airflow direction (suction or pressure).

Objective

The objective of the research presented here was to determine acceptable aeration strategies for farmer stock peanuts stored in conventional warehouses with and without headspace ventilation.

Procedure

Warehouse Description

Four 1/10th scale warehouses measuring 4.3 m long and 2.4 m wide with 0.6 m eave height and a 12:12 roof pitch were used in the study (Smith et al., 1989). Each warehouse holds 4 t of farmer stock peanuts. The aeration/ventilation regimes are summarized in table 1.

Warehouses 1 and 2 had only floor aeration systems. These peanuts were aerated at a rate of 0.31 $m^3\ min^{-1}\ t^{-1}$ of peanuts using three perforated ducts spaced evenly across the width of the warehouse, as shown in figure 1. A small centrifugal fan (model 4C012, Grainger, Albany, Ga.) was attached to each duct. The fans were mounted with the inlet attached

Table 1. Aeration and ventilation specifications for tests conducted in 1/10th scale model peanut warehouses.

	Warehouse			
	1	2	3	4
Warehouse volume (m^3)	12.7	12.7	12.7	12.7
Peanut capacity (t)	3.6	3.6	3.6	3.6
Aeration				
$m^3\ min^{-1}\ t^{-1}$	0.31	0.31	0.10	--
$m^3\ min^{-1}$	1.27	1.27	0.43	--
Number of ducts	3	3	1	0
Airflow direction	Down	Up	Up	None
Ventilation				
Air change min^{-1}	None	None	0.50	0.50
$m^3\ min^{-1}$			0.79	0.79

to the ducts on warehouse 1 so that air was drawn down through the peanuts. In warehouse 2, the fan outlet was attached to the duct to blow air up through the peanuts. A damper mounted in the duct and a gate over the exposed fan inlet/outlet was set so that each fan delivered approximately 0.43 $m^3\ min^{-1}$. The total airflow produced by all three fans was 1.27 $m^3\ min^{-1}$. The third warehouse had aeration and headspace ventilation. The duct system in warehouse 3 was similar to warehouses 1 and 2, except that only one duct down the middle of the warehouse was used. The fan was used to blow 0.1 $m^3\ min^{-1}\ t^{-1}$ (0.43 $m^3\ min^{-1}$) up through the peanuts. Ducts were sized so that the air velocity was less than the recommended maximum 10 $m\ s^{-1}$ (Loewer et al., 1994). The perforated surface area of the aeration ducts was designed for a maximum exit velocity of 0.13 $m\ s^{-1}$. The headspace was ventilated at the recommended rate of one air change of the headspace volume every 2 min (Smith et al., 1995). The fourth warehouse had only headspace ventilation at the recommended rate.

Instrumentation and Controls

Each of the model warehouses was instrumented with thermocouples (ANSI, type T) to measure headspace temperature (T_{head}), peanut temperature approximately 10 cm below the surface on the east (T_{east}) and west (T_{west}) sides of the pile, and roof temperature (T_{roof}). Relative humidity in the headspace (RH_{head}) was measured using a relative humidity probe (HMW40, Vaisala, Helsinki, Finland). Ambient temperature ($T_{ambient}$) and relative humidity ($RH_{ambient}$) were measured using a thermocouple (ANSI,

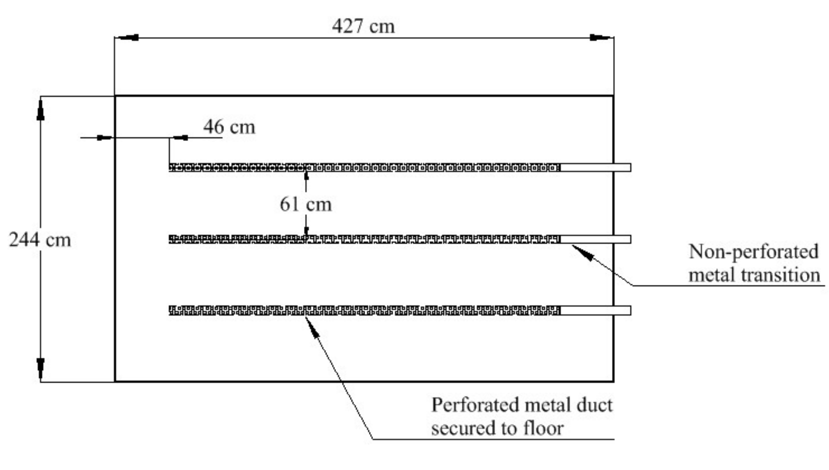

Figure 1. Aeration duct layout for 1/10th scale model peanut warehouse.

type T) and a humidity transmitter (HMD60, Vaisala, Helsinki, Finland) mounted in a gill radiation shield 1.5 m above the ground. All sensors were monitored continuously using a programmable logic controller (DirectLogic 305, Automation Direct, Atlanta, Ga.) and associated analog and thermocouple input modules. Data were recorded every 30 min.

All fans were controlled using the PLC and were based on measured temperatures and/or relative humidity. The headspace ventilation fans were operated according to the following criteria:

If: $T_{head} \geq 21.1^{\circ}C$,
Or: $RH_{head} \geq 80\%$,
Or: $RH_{head} \geq 60\%$ And: $(T_{head} - T_{roof}) \geq 7.2^{\circ}C$,
Then: Headspace fan is ON.
Else: Headspace fan is OFF.

The headspace temperature limit of 21°C relates to optimal temperature for the activity and reproduction of Indian meal moth, *Plodia interpunctella* (Hübner), and other stored product insects (Arthur, 1995). Research has shown that storing peanuts at a relative humidity greater than or equal to 80% may lead to excessive mold growth and potential aflatoxin contamination (Diener et al., 1982). Diener et al. (1982) also reported that aflatoxin was formed at low levels in living, immature, or broken seed after 84 days at 84% relative humidity and 30°C. The final criterion for turning on the fan was designed to minimize condensation on the roof and supporting structure. Examination of the psychrometric chart shows that the dewpoint temperature is approximately 7.2°C cooler than the dry bulb temperature at 60% relative humidity. These are the same control setpoints used in previous research by Butts and Smith (1994).

The aeration fans were controlled in two stages. The first stage was an initial cool down that depended on peanut $[T_{peanut} = (T_{east} + T_{west})/2]$ and ambient air temperatures and ambient relative humidity, as follows:

If: $T_{ambient} \leq T_{peanut}$
And: $RH_{ambient} \leq 80\%$,
Then: Aeration fan is ON.
Else: Aeration fan is OFF.

The upper limit on relative humidity was to prevent excessively moist air from being drawn into the peanuts. The equilibrium moisture content of peanut kernels at 80% relative humidity is approximately 10% wet basis (*ASAE Standards*, 2002; all moisture contents are presented as wet basis unless otherwise noted). Most farmer stock peanuts are placed in the warehouse at average moisture content less than 10%. However, single kernel moisture could be much higher (Dowell et al., 1993). Therefore, an upper limit of 80% relative humidity would allow the peanuts to continue to dry as they are aerated. The aeration fans were operated using the initial cool down rules for about the first 30 to 60 days of storage. After the initial cooling phase, a lower limit of 65% relative humidity was added to prevent overdrying. At 65% relative humidity, peanuts will equilibrate to approximately 7% moisture content. The rules for aeration fan operation during the maintenance phase are shown below:

If: $T_{ambient} \leq T_{peanut}$
And: $65\% \leq RH_{ambient} \leq 80\%$,
Then: Aeration fan is ON.
Else: Aeration fan is OFF.

Sampling and Data Analysis

Peanuts were locally produced, dug, harvested, cured, and marketed according to conventional practice. Peanuts harvested from farms within 25 km of Dawson, Georgia, during 2002 and 2003 were graded and marketed according to conventional practice. Warehouse loading was completed around the first of October both years. Four loads of farmer stock peanuts, each weighing approximately 4 t, were obtained from a local peanut buying facility. Using a hydraulic dump wagon on portable truck scales, peanuts were emptied from the wagon into a skid steer loader and transferred into the model warehouses. Approximately one-quarter of the peanuts from each load was placed in each warehouse to simulate the layering and mixing that normally occurs in commercial warehouses. Each load represented one of four layers in the warehouse. As peanuts flowed from the wagon into the loader bucket, 4.5 kg samples were obtained and placed in mesh bags from each wagon. Three samples were placed in each warehouse as each new layer was begun, and three samples were kept to evaluate the initial quality of peanuts. A total of 12 samples were placed in each warehouse in 2002. Eighteen samples were placed in each warehouse in 2003. The weight of peanuts placed in each warehouse from each load was recorded using portable truck scales.

While loading the 2002 crop peanuts, a small data logger (HOBO Pro H08-032-08, Onset Computer Corp., Bourne, Mass.) was placed in each of the samples from the first and fourth layers to record temperature and relative humidity. Data loggers were placed in one sample bag for each layer while loading the 2003 crop. These samples were placed in the center of the warehouse as each layer was completed.

The warehouses were unloaded by hand-transferring peanuts from the warehouse into portable bins for weighing. The samples placed in the warehouses during loading were retrieved, data loggers removed, and peanuts evaluated for quality. Unloading occurred in the spring to coincide with typical unloading dates for commercial warehouses.

All peanut samples were cleaned by separating the foreign material, loose shelled kernels, and pods. The percent foreign material and loose shelled kernels were determined. The whole pods were shelled using a Model 4 laboratory peanut sheller (Davidson and McIntosh, 1973). Size distribution of the shelled kernels was determined by sizing over slotted screens. The percent sound mature kernels (SMK), sound splits (SS), total sound mature kernels (TSMK), other kernels (OK), and damaged kernels (DK) were calculated based on screen sizes prescribed by federal-state inspection standards for runner-type peanuts (USDA, 2000). Kernel moisture content was measured using an electronic moisture meter (GAC 2000, Dickey-John, Inc., Auburn, Ill.).

After sizing, peanuts were recombined and evaluated for aflatoxin contamination. Shelled peanuts were ground in a vertical cutter mixer (model RSI6Y-1, Robot Coupe USA, Jackson, Miss.) for 7 min to produce a homogeneous paste. A 200 g subsample of paste was extracted with 400 mL of methanol/water (80:20, v/v), and the extract was filtered through Whatman No. 4 filter paper. Aflatoxins were quantified according to the liquid chromatographic method of Sobolev and Dorner (2002). Briefly, extracts were purified on a basic, aluminum oxide minicolumn, injected onto a Nova-PAK C_{18} column (150 × 3.9 mm; 4 micron; Waters

Table 2. Summary of weight loaded into and out of warehouses during the two-year aeration study.

		Warehouse 1	Warehouse 2	Warehouse 3	Warehouse 4	Date
2002						
Load-in[a]	(kg)	3398	3548	2970	3725	04 Oct. 02
Unload	(kg)	3474	3396	2880	3537	14 Apr. 03
Change	(kg)	76	−152	−90	−188	192 days
	(%)	2.2	−4.3	−3.0	−5.0	
2003						
Load-in[a]	(kg)	3346	3439	3233	3364	30 Sept. 03
Unload	(kg)	3323	3127	3182	3255	05 Apr. 04
Change	(kg)	−23	−312	−51	−109	187 days
	(%)	−0.7	−9.1	−1.6	−3.2	
Two−Year Average						
Load-in	(kg)	3372	3494	3102	3545	
Unload	(kg)	3399	3262	3031	3396	
Change[b]	(kg)	27 a	−232 b	−71 ab	−149 ab	190 days
	(%)	0.8 a	−6.7 b	−2.3 ab	−4.1% ab	

[a] Date that loading of layer 4 was completed. Load-in start dates were 17 Sept. 2002 and 26 Sept. 2003.
[b] Means in the same row followed by the same letter are not significantly different for P < 0.05.

Chromatography, Milford, Mass.), and eluted with a mobile phase of water/methanol/butanol (1400:720:25, v/v/v). Aflatoxins were detected with a fluorescence detector (model RF-551, Shimadzu, Kyoto, Japan) after postcolumn derivatization in a photochemical reactor (Aura Industries, New York, N.Y.). Individual aflatoxin concentrations were summed and are presented as total aflatoxin (ng) per g of peanuts.

The loan value of farmer stock peanuts is based on the percent total sound mature kernels (TSMK) and other kernels (OK) with deductions for excessive foreign material (FM), sound splits (SS), and damaged kernels (DK), as shown in equations 1 to 4 below. In the equations, the grade factor is rounded to the nearest whole percent prior to calculation:

$$\text{Loan value (\$/t)} = \%\text{TSMK}\times\$5.356+\%\text{OK}\times\$1.54-D_{SS}-D_{FM}-D_{DK} \quad (1)$$

$$D_{SS} = \begin{cases} 0 & ,\ \%\text{SS} < 2\% \\ (\%\text{SS}-4)\times\$0.88 & ,\ \%\text{SS} \geq 2\% \end{cases} \quad (2)$$

$$D_{FM} = \begin{cases} \$0.00 & ,\ \%\text{FM} \leq 4\% \\ (\%\text{FM}-4)\times\$1.10 & ,\ 4\% < \%\text{FM} \leq 11\% \\ \$7.70+(\%\text{FM}-11)\times\$1.65 & ,\ 11\% < \%\text{FM} \leq 15\% \\ \$14.30 & ,\ 15\% < \%\text{FM} \end{cases} \quad (3)$$

$$D_{SS} = \begin{cases} \$0.00 & ,\ \%\text{DK} \leq 1\% \\ \$3.74 & ,\ 1\% < \%\text{DK} \leq 2\% \\ \$7.70 & ,\ 2\% < \%\text{DK} \leq 3\% \\ \$12.10 & ,\ 3\% < \%\text{DK} \leq 4\% \\ \$27.50 & ,\ 4\% < \%\text{DK} \leq 2\% \\ \$44.00 & ,\ 5\% < \%\text{DK} \leq 6\% \\ \$66.00 & ,\ 6\% < \%\text{DK} \leq 7\% \\ \$88.00 & ,\ 7\% < \%\text{DK} \leq 10\% \\ \$110.00 & ,\ 10\% < \%\text{DK} \end{cases} \quad (4)$$

Peanut quality data were analyzed using analysis of variance for means separation. Because aflatoxin data were not normally distributed, they were subjected to Kruskal-Wallis analysis of variance on ranks.

Results and Discussion

Shrinkage

Table 2 summarizes the weights of peanuts loaded into and out of each warehouse. Over the two-year test, peanuts in warehouse 1 (downdraft aeration) showed an average increase in weight of approximately 0.8%. The gain was not

Table 3. Summary of peanut quality before and after storage for crop years 2002, 2003, and the two-year average.

	Grade Factor[a]	At Load-in	After Storage in Warehouse 1	2	3	4
2002	Total sound mature kernels (%)	74.4 a	74.6 a	72.4 b	72.9 b	73.4 ab
	Other kernels (%)	3.1 a	1.3 d	2.3 c	2.8 ab	2.5 bc
	Damaged kernels (%)	0 a	1.8 bc	2.3 c	1.3 b	1.2 b
	Loan value ($ t^{-1})	400.46 a	389.24 ab	382.15 b	388.62 ab	391.93 ab
	Moisture content (% w.b.)	6.1 a	5.9 a	6.1 a	5.5 b	6.0 a
	Aflatoxin (ng g^{-1})[b]	0 a	15 a	22 a	12 a	162 b
2003	Total sound mature kernels (%)	74.1 a	69.1 b	68.8 b	68.6 b	68.5 b
	Other kernels (%)	2.2 a	8.3 b	8.3 b	8.4 b	8.2 b
	Damaged kernels (%)	0 a	0.3 ab	0.6 b	0.8 b	0.8 b
	Loan value ($ t^{-1})	394.89 a	372.33 b	370.94 b	369.10 b	368.67 b
	Moisture content (% w.b.)	5.7 a	5.6 b	5.3 c	5.1 d	5.2 d
	Aflatoxin (ng g^{-1})[b]	0 a	4.9 a	0 a	0 a	0 a
Two−Year Average	Total sound mature kernels (%)	74.2 a	72.4 b	71.0 c	71.2 c	71.5 bc
	Other kernels (%)	2.7 a	4.1 b	4.7 bc	5.0 c	4.8 bc
	Damaged kernels (%)	0 a	1.2 bc	1.6 c	1.1 b	1.0 b
	Loan value ($ t^{-1})	397.68 a	382.48 b	377 67b	380.81 b	382.63 b
	Moisture content (% w.b.)	5.9 a	5.7 ab	5.8 ab	5.4 c	5.6 b

[a] Quality factors in the same row followed by the same letter are not significantly different for P ≤ 0.05.
[b] Median aflatoxin concentrations tested for significant differences using Kruskal-Wallis one-way ANOVA on ranks.

accounted for by gains in moisture content (table 3), as the moisture content of the samples did not change significantly during the storage period in either year. The moisture content of the samples is probably not indicative of the moisture content of the peanuts in the warehouses. Samples were stored on a pallet in ambient conditions for approximately three weeks before shelling; therefore, the moisture content is more indicative of sample storage conditions. The 2% gain for the 2002 crop was probably due to an infestation of ants building a large mound in the south end of the building and its weight being included in the bailout weight. Since the infestation did not involve the samples initially placed in storage, this added foreign material was included in the unloading weight. Warehouses 2, 3, and 4 averaged 6.7%, 2.3%, and 4.1% loss in weight, respectively.

Peanut Quality

During the two-year study, the peanut kernel size distribution changed during storage (table 3). TSMK are undamaged whole kernels and kernel halves that ride a prescribed slotted (whole kernels) or round (halves) screen and are marketed as edible peanuts. TSMK is the predominant factor in determining the value of a load of peanuts (eq. 1). Generally, as the moisture decreases from the initial purchase, kernel size will decrease and more peanuts will fall through the screen used to determine TSMK, thus reducing their value. On average, peanuts stored in all four warehouses had significant decreases in TSMK when compared with the initial percent TSMK. Percent TSMK decreased the least to 72.4% in warehouse 1 (downdraft aeration) from the original 74.2%. TSMK decreased to 71.0% and 71.2% in warehouses 2 (updraft aeration) and 3 (aeration + ventilation), respectively. The decrease of TSMK stored in warehouse 4 (ventilation only) was similar to that of peanuts stored in warehouse 1. OK are whole and broken kernels that fall through the prescribed-size slotted screen and when combined with the damaged kernels are crushed for oil. Percent OK is expected to increase during storage because of physical shrinkage of the kernels as peanuts equilibrate to lower moisture contents, and percent OK should increase proportional to the decrease in TSMK. The two-year average showed that percent OK increased by about two percentage points in all four warehouses compared with the initial sample. Peanuts stored in warehouse 1 had the smallest increase in percent OK to 4.1%, percent OK in warehouse 3 increased to 5.0%, and percent OK increased to 4.7% and 4.8%, respectively, in warehouses 2 and 4. DK increased in all four warehouses.

Data from both years showed a numerical decrease in value during storage. However, in 2002, only the peanuts in warehouse 2 showed a significant change in value from the initial value. During 2003, the decrease in value for all four warehouses was significant. There was no significant difference in value among warehouses in either year. Over the two-year period, the stored peanuts lost an average of 4.6% of their original value, and the loss ranged from 4.2% in warehouse 1 to 5.3% in warehouse 2.

According to outgoing quality standards (USDA, 2005), peanuts are considered free from aflatoxin if aflatoxin

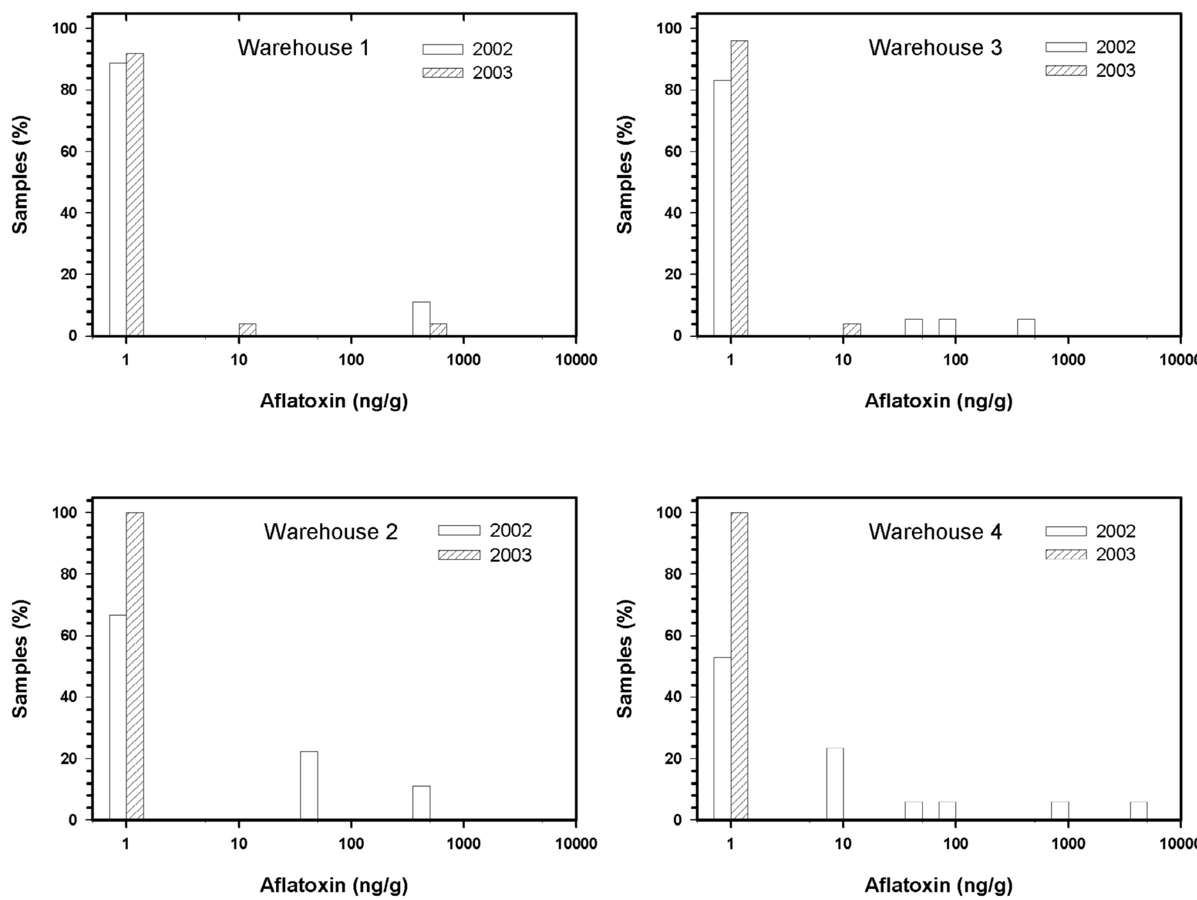

Figure 2. Percent of peanut samples with various levels of aflatoxin concentration after storage for crop years 2002 and 2003.

concentration is 15 ng/g or less. If the aflatoxin level is 300 ng/g or less, then the peanuts can be reprocessed in an effort to meet the edible quality standard. If aflatoxin is greater than 300 ng/g, then they must be crushed for oil or destroyed. Based on these data, peanuts from the 2002 crop stored in warehouse 4 would have needed considerably more processing to make them suitable for the edible market.

Aflatoxin was below detectable limits in all but one of the initial peanut samples in both years of the study. A large number of the samples from all four warehouses had less than 1 ng/g aflatoxin after storage for both crop years. Standard analysis of variance tests were invalid because the data were not normally distributed (fig. 2). A Kruskal-Wallis one-way analysis of variance on ranks was used to detect significant difference in the median aflatoxin levels.

In the initial samples from the 2002 crop, one sample had an aflatoxin concentration of 0.7 ng/g. During storage, slight numerical, but non-significant, increases in aflatoxin were noted in warehouses 1, 2, and 3. Approximately 89% of the samples stored in warehouse 1 had less than 15 ng/g aflatoxin, and 11% had between 15 and 300 ng/g aflatoxin. Only 72% of the samples stored in warehouse 2 had less than 15 ng/g, and 28% had aflatoxin concentration between 15 and 300 ng/g. Eighty-three percent of the samples stored in warehouse 3 had 15 ng/g or less aflatoxin. No samples stored in warehouses 1, 2, or 3 had aflatoxin in excess of 300 ng/g. Based on outgoing quality standards, all the peanuts in warehouses 1, 2, and 3 could have been processed sufficiently to remove the aflatoxin-contaminated peanuts and used in the edible market. However, 11% of the samples stored in warehouse 4 had an aflatoxin concentration in excess of 300 ng/g. The increase in median aflatoxin levels to 162 ng/g in warehouse 4 was significant ($P \leq 0.05$). No other significant differences were found (table 3).

At least 90% of the 2003 crop year samples from all four warehouses had 1 ng/g aflatoxin or less. Warehouse 1 was the only warehouse that had one sample with 52 ng/g aflatoxin. All remaining samples had less than 15 ng/g aflatoxin. A Kruskal-Wallis one-way analysis of variance on ranks showed no significant difference in the median aflatoxin levels from the 2003 crop. Based on these data, all 2003 crop peanuts stored in warehouses 2, 3, and 4 could be used for the edible market with no additional processing. Approximately 8% of the peanuts from warehouse 1 would have needed additional processing to meet the outgoing quality standards.

Based on low levels of aflatoxin in the 2002 pre-storage samples, it is assumed that toxigenic molds were present in the peanuts prior to storage. During storage, moisture and temperature conditions reached levels conducive to aflatoxin production. The lower levels of aflatoxin in warehouses 1, 2, and 3 indicate that temperature and moisture conditions were at dangerous levels for a shorter period of time in the aerated warehouses.

Storage Environment

Ambient temperatures were similar during both storage seasons (table 4). The average ambient temperature during the 2002 storage season was 13.6°C, compared to 16.5°C for the 2003 season. The average peanut temperatures were about the same for all warehouses during both storage seasons and averaged approximately 14°C. The standard deviation of the peanut temperatures was approximately the same in all four warehouses, with the standard deviation being slightly higher for the 2002 season.

Table 4. Summary of ambient and average peanut temperatures during the storage periods for the 2002 and 2003 crops.

		Ambient Temp. (°C)	Warehouse Temperature (°C)			
			1	2	3	4
2002	Average	13.6	13.5	14.2	13.8	13.8
	Std. Dev.	7.8	5.7	5.4	5.3	5.6
	Maximum	33.3	31.7	32.0	30.8	30.6
	Minimum	−10.6	−0.1	2.1	1.3	0.7
2003	Average	16.5	13.6	14.2	14.4	13.1
	Std. Dev.	8.0	4.8	4.7	4.6	5.3
	Maximum	35.8	30.3	34.0	28.7	28.7
	Minimum	−2.9	7.4	6.2	8.6	5.8

Headspace ventilation systems rely on differences in air density and temperature of the air in the headspace and the peanut mass to cool the bulk and remove excess moisture. In these small scale models, headspace ventilation would cool the mass more quickly than in commercial operations where peanut depths are approximately 14 m compared to 1.5 m in the models.

After loading the first layer of peanuts into the warehouse, the aeration fans helped reduce the maximum peanut temperature during the first three days of storage (fig. 3). The maximum observed temperature in warehouses 1 and 2 was lower than the maximum temperature observed in warehouse 3. The maximum peanut temperature of approximately 47°C in layer 1 during the first five days appeared in warehouse 4. The maximum temperature in warehouse 1 was 35°C. This difference was expected because the fan for the headspace ventilation system is located at the peak of the gable end of the warehouse, drawing air in the opposite gable and traveling near the ridge of the building. Prior to mid-afternoon on 19 September 2002, the maximum temperature difference among the warehouses was less than 3°C. During the first five days of storage, the minimum temperature appeared to be about the same for all aeration treatments. During the second five days of storage, the maximum temperatures of layer 1 were all about the same (fig. 4). Less than 1°C difference in temperature was observed among warehouses.

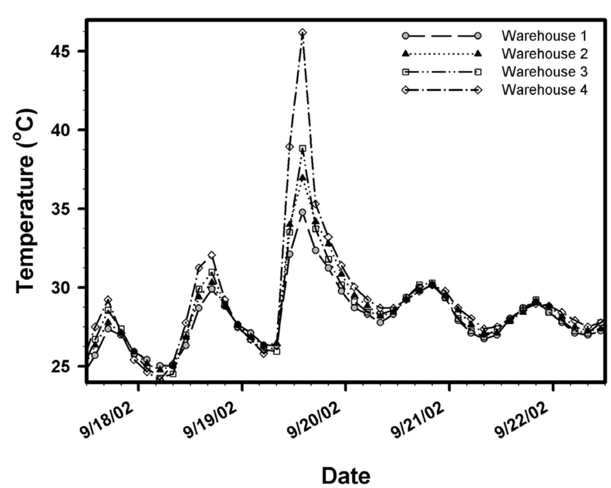

Figure 3. Peanut temperature on the floor of the warehouses during the first five days of storage of the 2002 crop.

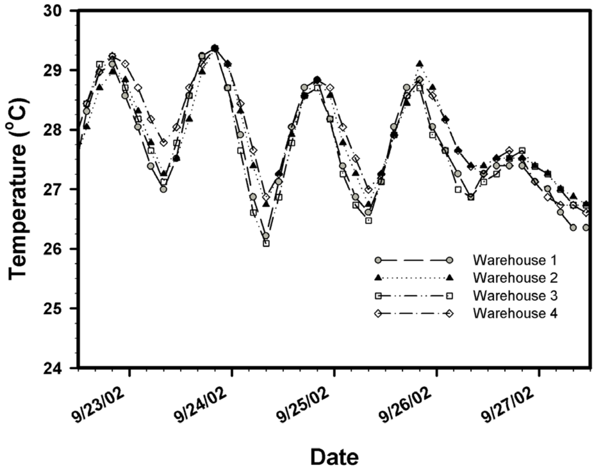

Figure 4. Temperature of first layer of peanuts during days 5 to 10 of storage period of the 2002 crop.

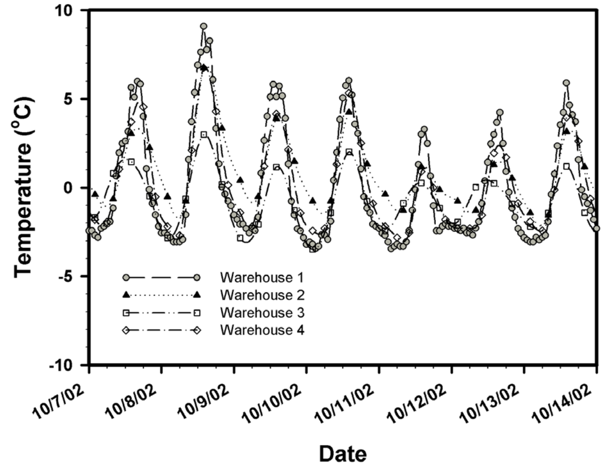

Figure 6. Temperature difference between top and bottom layers (top minus bottom) of peanuts in model warehouses during week 4 of storage of the 2002 crop.

During the fourth week of storage, approximately two weeks after loading was completed (table 2), the top layer of peanuts in warehouse 1 appeared to have a consistently higher temperature than the other warehouses (fig. 5). The warehouse with both aeration and ventilation, warehouse 3, tended to have the most consistent temperature in the top layer.

During the fourth week of storage, the temperature difference between the top and bottom layers of the warehouses ranged from the top being 9°C warmer than the bottom to the top being about 3°C cooler than the bottom. Warehouse 1, with downdraft aeration, and warehouse 4, with only headspace ventilation, tended to have the smallest temperature gradient from top to bottom. The average temperature differences (top minus bottom) for warehouses 1 through 4 were 0.1°C, 0.9°C, −0.8°C, and 0.2°C, respectively (fig. 6). However, the temperature difference varied most in warehouse 1, as indicated by the standard deviation of 3.2°C. The standard deviations of the temperature difference for warehouses 2, 3, and 4 were 2.0°C, 1.6°C, and 2.6°C, respectively. Similar trends were noted during the 14th week of storage from 1 to 8 December 2002 (fig. 7). However, the top layer of the peanut pile tended to be cooler than the floor layer most of the time in all four warehouses. The temperature difference between the top and bottom layers averaged −3.0°C, −2.0°C, −3.1°C, and −3.3°C for warehouses 1 to 4, respectively. Warehouses 2 and 3 had the smallest standard deviation of 2.2°C and 2.3°C, respectively. The standard deviation was 3.3°C in warehouses 1 and 4.

Over the entire storage period, the difference between the top and bottom layer temperatures averaged slightly less than zero for all for warehouses. The temperature differences varied from −9° to 11°C for all four warehouses. Warehouses 2 and 3 had the smallest season-long standard deviations (3.3° and 3.2°C, respectively). The standard deviations for the temperature differences in warehouses 1 and 4 were 3.8° and 4.0°C, respectively.

Peanuts from the 2003 crop stored in warehouse 2 cooled most rapidly during the first eight days of storage (fig. 8). The temperature at the center of the peanut mass decreased approximately 5°C during the first 12 h of storage. Peanuts stored in warehouse 3 with the combined aeration/ventilation system also cooled fairly rapidly compared to those stored in warehouses 1 and 4. Peanut temperature decreased approximately 2°C during the first 12 h of storage in warehouse 3.

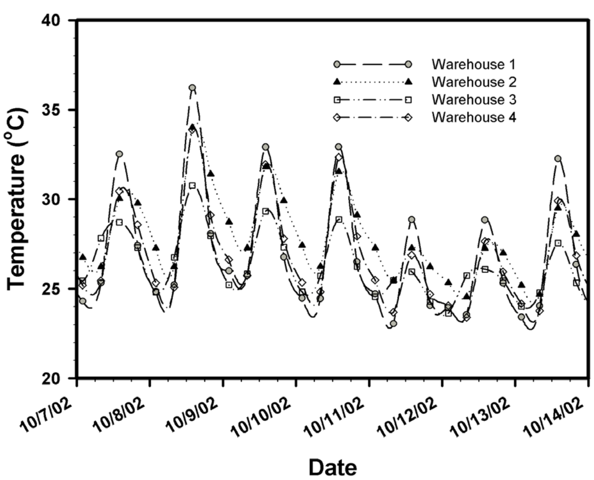

Figure 5. Peanut temperatures of the top layer in model warehouses during the fourth week of storage of the 2002 crop.

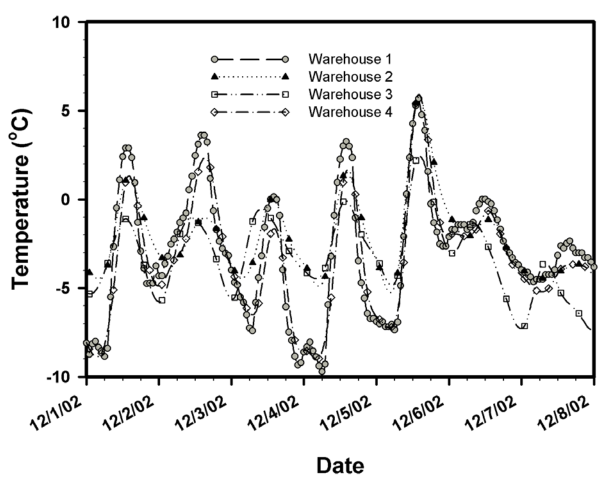

Figure 7. Temperature difference between top and bottom layers (top minus bottom) of peanuts stored in model warehouses during week 14 of storage of the 2002 crop.

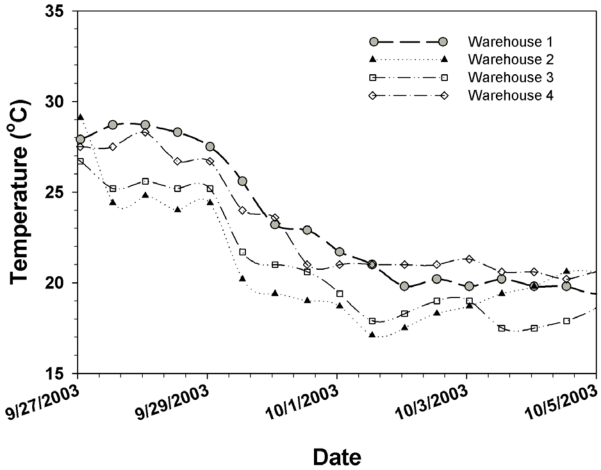

Figure 8. Temperature at the center of the peanut mass during the first eight days of storage for the 2003 crop.

The temperature at the center of the peanut mass in warehouses 1 and 4 remained the same or increased slightly during the first 36 h of storage before beginning to cool. After eight days, the peanut temperature was approximately 20°C in all four warehouses. The season-long average temperature was approximately the same for all four warehouses during the 2003 storage period.

On average, very little difference in the storage environments could be seen in the aeration/ventilation regimes used in this study. The warehouses with at least some aeration tended to cool the core of the peanut mass more quickly than the warehouse without aeration. In commercial warehouses, removing the excess heat and moisture is essential for minimizing the time that conditions are favorable for the production of aflatoxin. In this study, the only warehouse that had a significant increase in aflatoxin was the warehouse with only headspace ventilation. The temperature data in this study indicated that downward aeration may require more airflow to decrease the temperature gradients from the upper to the lower layers. The data also indicated that a single tunnel down the middle of the warehouse may be adequate for the initial cool-down of the peanuts in a commercial warehouse. Many commercial warehouses are loaded using an overhead conveyor in the ridge of the building. Loading the warehouse by layering the peanuts from end to end is the recommended practice (APSA, 2005) and facilitates covering an aeration duct down the center of the warehouse. As soon as the duct is covered, the aeration fan can be operated and cooling can begin. Therefore, in commercial practice, retrofitting an existing warehouse with a single aeration duct would be practical and beneficial.

Summary and Conclusion

A two-year study was conducted in which farmer stock peanuts were stored in 1/10th scale model warehouses with various aeration and ventilation treatments. Peanuts were loaded into each warehouse in the fall and stored for about 190 days. Peanuts stored with aeration, generally cooled faster than those stored without aeration. While storing peanuts from the 2002 crop, aflatoxin increased significantly in the warehouse without aeration. However, aflatoxin contamination was not a factor in the 2003 storage season. Value change based on kernel size distribution was not significantly affected by aeration. Aeration minimized the production of aflatoxin in the year that aflatoxin was detected in the initial samples. An aeration rate of 0.31 m^3 min^{-1} t^{-1} was sufficient for proper aeration when used without headspace ventilation. The reduced aeration rate of 0.10 m^3 min^{-1} t^{-1} in conjunction with headspace ventilation cooled the center of the peanut mass sufficiently to reduce the risk of aflatoxin production in storage. Headspace ventilation with aeration reduced the temperature difference between the top and bottom layers of peanut during storage.

Based on this research, aeration systems reduced the risk of aflatoxin production in farmer stock warehouses. Delivering 0.10 m^3 min^{-1} t^{-1} through a duct down the center of the warehouse appeared to be as beneficial in reducing the risk of aflatoxin contamination during storage as fully aerating at a rate of 0.31 m^3 min^{-1} t^{-1}. This would make retrofitting existing warehouses more practical, especially if installing the aeration duct in the current concrete floor. Further research is needed with more detailed temperature measurements to determine the differences in pressure and suction aeration systems in farmer stock peanuts.

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