Market System Model to Predict the Effects of Regulatory and Processing Practices on the Removal of Aflatoxin from Peanuts[1]

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ABSTRACT

A spreadsheet model was developed to predict the aflatoxin distribution among peanut lots in the market system from farmer stock marketing through storage, shelling, and blanching. The model calculates the aflatoxin distribution among lots after each major regulatory and processing stage in the market system from the buying point to the manufacturer. Model development is based on statistical and mathematical relationships derived from previous research on the effects of sampling plans and processing methods on the change in aflatoxin levels in peanuts. The USDA and the peanut industry can use the model as a tool to compare and evaluate the efficacy of proposed new regulations and processing methods on removing aflatoxin without actual costly implementation. The model also points out potential areas where information is missing and research is needed to better manage aflatoxin-contaminated peanuts. The model is used to evaluate the peanut market system where farmers' stock peanuts are chemically tested for aflatoxin.

Key Words: Aflatoxin, *Arachis hypogaea*, blanching, food safety, processing, sampling, toxins.

The peanut industry is unique among agricultural commodity industries in having a marketing agreement for the control of aflatoxin. Prior to the 2002 crop year, the USDA Marketing Agreement, administered by the Peanut Administrative Committee (PAC), defined procedures for the control of aflatoxin in peanuts (9). The PAC consisted of a permanent manager, a representative of the Secretary of Agriculture, and 18 committee members. The committee members consist of three growers and three shellers from each of the three major growing areas—Virginia-Carolina, Southeast, and Southwest. The PAC was financially supported by assessments of shellers based upon the volume of peanuts they purchase. With the new 2002 farm bill, PAC was abolished and a Peanut Standards Board (PSB) was established. The PSB is similar to PAC, but can only advise the Secretary of Agriculture concerning how peanuts are marketed in the U.S.

Shellers play a major role in the control of aflatoxin from the time peanuts are purchased from the farmer (farmer stock peanuts) until the raw shelled peanuts are sold to a manufacturer of consumer-ready products. Shellers attempt to manage the aflatoxin problem by placing farmer stock (FS) peanuts with higher risk of contamination in separate storage facilities, using good management practices during storage, and using various sorting techniques to remove aflatoxin-contaminated kernels during shelling processes. As a result, shellers deliver peanuts to manufacturers of consumer-ready products that are either aflatoxin free or below the U.S. Food and Drug Administration (FDA) guideline of 20 ppb. Highly contaminated lots are diverted for use as oil.

The USDA Marketing Agreement required that peanuts be inspected for aflatoxin at two locations within the market system. First, FS peanuts are inspected for the aflatoxin-producing fungi, *Aspergillus flavus* (Link), when farmers sell their peanuts to a sheller at the buying point. Some shellers chemically test FS peanuts as part of their own in-house aflatoxin management procedures. Second, raw shelled peanuts are sampled and chemically tested for aflatoxin after the shelling process.

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When farmers sell their peanuts at the buying point to a sheller, the lot is graded to determine the support price and the possible presence of aflatoxin (5). As part of the grading process, peanut kernels in a 1800-g grade sample are inspected for the aflatoxin producing fungi *A. flavus*. This aflatoxin inspection method for FS peanuts is often called the visual *A. flavus* or VAF method (6). If one or more kernels in the grade sample are found with the fungi, the lot is classified segregation 3, diverted from food use, and crushed for oil. Lots with no *A. flavus* kernels, but more than 2% damaged kernels or more than 1% concealed damaged kernels in the grade sample, are classified segregation 2. Segregation 2 lots usually are crushed for oil. Other peanut lots are classified segregation 1 and used in the edible market (4).

Most segregation 1 peanuts are processed as either in-shell or raw shelled peanuts. Raw shelled peanuts account for about 75% of the total market (10). The shelling processes includes removing foreign material, removing or separating the shell or hull from the kernels, separating shelled kernels into several commercial size categories, and removing damaged or discolored kernels by using electronic color sorters. The USDA requires that all raw shelled lots must be chemically tested for aflatoxin before being shipped to a manufacturer. Lots that exceed the USDA-defined aflatoxin tolerance of 15 total ppb are reprocessed in order to reduce the aflatoxin content. The peanut industry established an aflatoxin tolerance (15 ppb) that is lower than the FDA guideline of 20 ppb. Processing options include (a) sending the peanuts back through the shelling plant (remilling), (b) sending the peanuts to a blanching facility (the blanching process is a two-step process where skins are removed from the kernel and damaged or discolored kernels are removed from the lot using electronic color sorters), and/or (c) crushing the peanuts for oil. Since 1990, a larger percentage of shelled peanut lots that exceed the USDA aflatoxin tolerance are sent to blanching facilities.

There has been an interest by all segments of the peanut industry (producers, shellers, and manufacturers) to improve the aflatoxin inspection program for FS peanuts by replacing the VAF method with a direct measure of aflatoxin (chemical testing). Numerous feasibility and scientific studies have been conducted to provide information that would help USDA design an aflatoxin- sampling program to replace the VAF method for FS peanuts (1, 17, 18, 19, 20).

The peanut industry has discussed the design of an aflatoxin sampling plan for FS peanuts. Decisions concerning the number and size of samples, number and magnitude of aflatoxin tolerance values, and possible monetary penalties and premiums for farmers based upon aflatoxin levels have yet to be decided by USDA and the peanut industry. A particularly sensitive issue concerning the aflatoxin sample design is the number and magnitude of aflatoxin tolerances. Producers desire a tolerance that will not reject an excessive number of their lots. On the other hand, shellers and manufacturers want aflatoxin tolerances that accept peanuts into the market system that meet the FDA legal limit of 20 ppb after processing. Defining aflatoxin tolerances for FS sampling plan also should take into account other marketing aspects such as the efficiency of shelling processes to reduce aflatoxin in FS lots. Also, USDA and the peanut industry must decide how to best partition its resources between aflatoxin sampling plans for FS and shelled peanuts. For example, if an aflatoxin sampling plan is designed for FS peanuts, perhaps a less restrictive and cheaper aflatoxin sampling plan would be acceptable for shelled peanuts since a FS sampling plan would remove many of the highly contaminated lots from the market system.

A method needs to be developed to assist USDA and the peanut industry to predict the effect of USDA aflatoxin regulations for FS and raw shelled peanuts, as well as other possible process changes on the reduction of aflatoxin in peanut lots purchased by manufacturers or exporters. The objective of this study was to develop a peanut market system model that would predict the effects of specific USDA aflatoxin regulations and market processing practices from the buying point to the manufacturer on the distribution of peanut lots according to their aflatoxin concentration.

Materials and Methods

There are six major stages of the peanut market system, from the buying point to the manufacturer, that have an effect on the amount of aflatoxin found in peanut lots (Fig. 1). The market system model was designed to incorporate these six stages. The market system model was developed as a spreadsheet model so that the aflatoxin distribution among lots marketed in a given crop year could be computed after each of these six market stages. An aflatoxin distribution among lots (lot distribution) describes how many (or what percentage) of the total lots marketed or processed at any stage of the market system in a given crop year are at specific aflatoxin concentrations. Aflatoxin concentrations are recorded in integer values (0, 1, 2, max.). Each of the six market stages is described below.

1. Farmer Stock Lot Distribution. Historical information on the aflatoxin distribution among FS lots is almost nonexistent due to the fact that no USDA aflatoxin regulations have existed to chemically test FS lots for aflatoxin. The

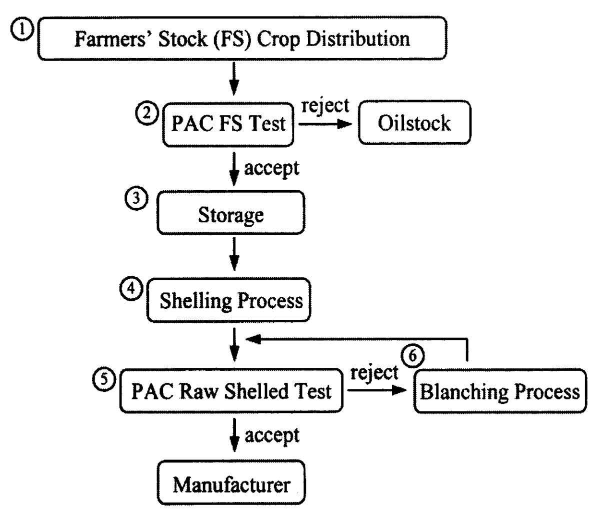

Fig. 1. Schematic diagram of the six major stages of the peanut market system.

American Peanut Council promoted an industry-wide program in 1990 to study the feasibility of measuring aflatoxin in samples from FS peanuts during the grading process at the buying point (1). A total of 3677 lots were tested for aflatoxin from five buying points across all three growing regions. A USDA grade sample was removed from each lot, the entire grade sample (excluding foreign material) is inspected for kernels with *A. flavus* and tested for aflatoxin. The number of lots measured, the average aflatoxin concentration, and standard deviation among the lot aflatoxin values at each of the five buying points are shown in Table 1. The average aflatoxin among lots marketed at each of the five buying points varied greatly and provided a wide range of FS lot distributions that can be used as inputs to the market system model.

Table 1. Estimates of aflatoxin in farmer stock lots tested at five buying points in the United States.

Buying point	Lots tested	Avg aflatoxin	Standard deviation
	no.	ppb	ppb
1	739	11	53
2	329	15	61
3	1431	224	440
4	811	414	294
5	283	617	356
Total	3677		

The negative binomial distribution was used to simulate a FS lot distributions for a given crop mean (14). The parameters of the negative binomial can be calculated from the mean and standard deviation (17). The mean and standard deviation among lots marketed at each of the five buying points are plotted in a full-log plot in Figure 2. A regression analysis indicated that the standard deviation (SD) is a function of the crop mean (M), as follows:

$$SD = 15.9\ M^{0.52} \qquad \text{[Eq. 1]}$$

with a correlation coefficient of 0.92. By specifying M, Equation 1 was used along with the negative binomial distribution to compute a FS lot distribution for the market system model. The effect of various crop contamination levels (M) on aflatoxin in peanut lots at various stages along

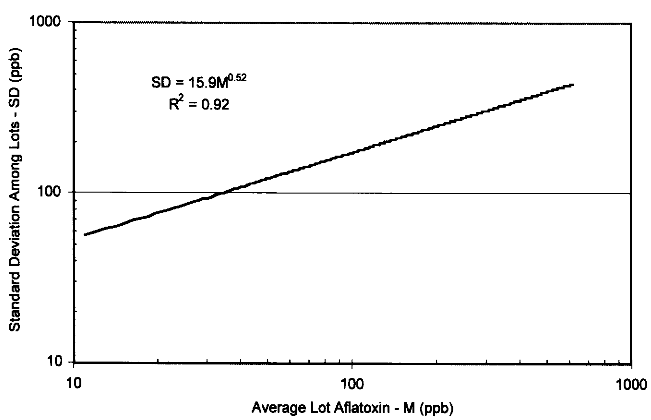

Fig. 2. Mean and standard deviation among lots marketed at each of five buying points in the United States.

the market system can be investigated using Equation 1 and the negative binomial distribution.

For this study, it is assumed that about 350,000 farmer stock lots are marketed by producers each crop year. The distribution among the 350,000 lots according to their aflatoxin concentration defines the initial or starting crop distribution for the market system model.

2. USDA FS Sampling Plan. The first location in the market system where the Federal State Inspection Service (FSIS) currently inspects the 350,000 FS peanut lots for possible aflatoxin contamination is at the buying point using the VAF method. Currently the VAF test is used to classify lots into segregation 1 and segregation 3 categories. A sampling plan (defined by a sample size, sample preparation method, analytical method, and tolerance values) that measures aflatoxin directly in samples taken from the lot would classify the 350,000 lots into two or more categories based upon the aflatoxin concentration in samples.

The peanut industry and USDA are considering replacing the current VAF method with a sampling plan that measures aflatoxin in samples taken from FS lots sold at the buying point. Under the proposed changes, each lot in the crop distribution would be chemically tested for aflatoxin by FSIS at the buying point. An aflatoxin-sampling plan with one or more aflatoxin tolerances will classify all farmer stock lots into two or more categories. The performance of a sampling plan is described by acceptance probabilities or by an operating characteristic (OC) curve. An OC curve predicts the percent lots at a given lot concentration that will test less than a defined tolerance (20). Methods developed by researchers were used in the model to compute OC curves for sampling plans that measure aflatoxin in FS peanuts (17, 18, 19, 20).

3. Storage of Farmer Stock Peanuts. Most FS lots are placed into warehouses after they are classified into a specific category by either the VAF method or an aflatoxin-sampling plan. For the model, it is assumed that all FS lots are warehoused. When FS lots are placed into a warehouse, the lots are commingled or combined, which alters the aflatoxin distribution among lots going into the warehouse. Eventually, about 30,000 shelled lots are created from the 350,000 FS lots each crop year for a ratio of FS lots to shelled lots of about 12:1. As a result, the distribution of FS lots going into a warehouse is changed by randomly combining 12 FS lots into one lot for shelling purposes.

To estimate the new aflatoxin distribution of commingled FS lots coming out of the warehouse, a statistical method (called the commingle routine) was developed and used to randomly combine 12 FS lots and make one larger lot for the shelling plant process. A method, which computed the joint probability distribution of the sum of two random variables, was developed to simulate commingling lots from an accepted FS lot distribution. Lots can be repeatedly paired to simulate the commingling of 2^n lots to create a commingled distribution from the accepted FS lot distribution.

In Table 2, a simple example of commingling pairs of lots illustrate how the joint probability is used to simulate commingling. The original lot distribution ranges in concentration from 0 to 3 ppb in units of 1 ppb (Table 2). The proportion of lots at 0, 1, 2, and 3 ppb are p_0, p_1, p_2, and p_3.

Table 2. Simple example of joint probability used to simulate commingling.

Lot concentration ppb	Avg[a]	Probability	
		Accepted farmer stock crop distribution	
0		p_0	q_0
1		p_1	q_1
2		p_2	q_1
3		p_2	q_3
		Commingling two lots into one lot	
0	0.0	$p_{0.0} = p_0q_0$	
1	0.5	$p_{0.5} = p_1q_0 + p_0q_1$	
2	1.0	$p_{1.0} = p_2q_0 + p_1q_1 + p_0q_2$	
3	1.5	$p_{1.5} = p_3q_0 + p_2q_1 + p_1q_2 + p_0q_3$	
4	2.0	$p_{2.0} = p_3q_1 + p_2q_2 + p_1q_3$	
5	2.5	$p_{2.5} = p_3q_2 + p_2q_3$	
6	3.0	$p_{3.0} = p_3q_3$	

[a]Average = sum/2.

The joint probability distribution of the sum of two lot ppb values is shown in Table 2. The number of points in the commingled lot distribution is doubled because averaging the sum of two lot concentrations created lots with 0.5 ppb units. To maintain 1 ppb units, half the 0.5 probability is added to zero probability and half the 0.5 probability is added to the 1 probability. This procedure of splitting probability for the 0.5 ppb is continued until the commingled lot distribution is collapsed back to 0, 1, 2, and 3 ppb as the original accepted lot distribution. An assumption is made in this study that Good Warehouse Practices are used to prevent an increase in aflatoxin concentration in lots while in storage.

4. Shelling Processes. Farmer stock peanuts are removed from the warehouse and taken into the shelling plant. Shelling processes include (a) removal of foreign material, (b) separation and removal of loose shelled kernels (LSK) from intact peanut pods, (c) shelling or hull removal, (d) electronic color sorting to remove discolored or damaged kernels, and (e) sizing kernels into several grade categories. Three FS grade categories (LSK, small, and damaged kernels) are considered poor quality peanuts. Studies have shown that aflatoxin is more likely to be found in these three FS peanut grades components than sound mature kernels (3, 7, 19). The aflatoxin concentration of each commingled FS lot is reduced in the shelling plant due to removal of LSK, removal of small kernels (kernel sizing), and removal of discolored or damaged kernels (electronic color sorting). About 30,000 shelled lots of different market grades (kernel sizes) and market types (runner, spanish, virginia, or valencia) are given "positive lot identifications" by shellers each crop year. The new shelled lot distribution is then sampled and tested for aflatoxin by USDA.

There are limited scientific studies that measured the percent reduction in aflatoxin due to shelling plant processes (2). In a single study, a FS lot with an estimated 217 ppb total aflatoxin was reduced to 25 ppb in medium-runner shelled peanuts after going through all shelling plant processes (2). This was an 88% reduction in aflatoxin due to all shelling plant processes combined. It is assumed that the 88% reduction is not a constant across all FS lot concentrations, but differs with the aflatoxin concentration of the FS lots going into the shelling plant. Communications between the authors and shellers indicate that percentage aflatoxin reduction in the shelling plant is greater for FS lots with high concentrations than lots with low concentrations. Results from the one shelling study and from studies that measured the aflatoxin reduction in blanched lots were used to estimate the aflatoxin reduction expected from shelling processes over a wide range of lot concentrations. It was assumed that the functional relationship between aflatoxin in lots before and after shelling processes is similar to that developed for the blanching process; only the coefficients would be different. Therefore, the aflatoxin in lots after shelling (AS) could be predicted from the aflatoxin in lots before shelling (BS) using Equation 2:

$$AS = a * BS^{b} \qquad \text{[Eq. 2]}$$

where a and b are constants. The percentage aflatoxin reduction due to shelling processes (RS) is defined as:

$$RS = 100 * (BS\text{-}AS)/BS \qquad \text{[Eq. 3]}$$

Substituting Equation 2 into 3 gives:

$$RS = 100*[1\text{-}(a * BS^{(b\text{-}1)})] \qquad \text{[Eq. 4]}$$

From the shelling study mentioned above, AS = 25 ppb, BS = 217 ppb, and RS = 88%. There is not enough data from this one study to calculate both the "a" and "b" coefficients from the above values of AS, BS, and RB. Therefore, "a" in Equation 2 was arbitrarily set equal to 1. Then "b" was determined to be 0.6 by solving Equation 2 for BS and AS values of 217 and 25, respectively. Equation 4 is then used to simulate the reduction of aflatoxin concentration in lots in the commingled lot distribution due to shelling plant processes.

5. USDA Raw Shelled Sampling Plan. USDA samples and chemically tests each shelled lot for aflatoxin after shelling plant processes. Before shelled lots can be shipped to a manufacturer of consumer-ready products, they must test less than the USDA aflatoxin tolerance. The USDA sampling plan is a sequential plan that uses up to three 22-kg (48 lb) samples and a final accept/reject limit of 15 total ppb to accept or reject each shelled lot (16). Methods developed by researchers (13, 15) were used in the model to evaluate the accept/reject probabilities associated with the USDA aflatoxin-sampling plan for shelled peanuts. Two new-shelled lot distributions are created by the USDA aflatoxin-sampling plan for raw shelled peanut lots. The first lot distribution consists of shelled lots that pass the USDA aflatoxin test and are shipped to a manufacturer of consumer-ready products (accepted shelled lot distribution). The second lot distribution consists of shelled lots that fail the USDA aflatoxin test (rejected shelled lot distribution). The USDA will try to reduce the aflatoxin concentration of shelled lots that fail the USDA aflatoxin test to acceptable levels using remilling and/or blanching processes.

6. Blanching Processes. For the model, it is assumed that all shelled lots that fail the USDA test are blanched. The blanching process is a two-step process that consists of removing the skin from the kernel and using electronic color sorters to remove damaged or discolored kernels (8). The efficiency of the blanching process has been studied (11) and the aflatoxin reduction (RB) was shown to be a function of the aflatoxin concentration in the lot before blanching (BB). The aflatoxin in shelled lots after blanching (AB) is described by the Equation 5 as:

$$AB = 1.8 * BB^{0.18} \quad \text{[Eq. 5]}$$

The percentage aflatoxin reduction due to blanching (RB) is shown in Equation 6.

$$RB = 100[1-(1.8*BB^{-0.82})] \quad \text{[Eq. 6]}$$

The blanching process reduces the aflatoxin concentration in each rejected shelled lot (Equation 5) that failed the USDA aflatoxin test after shelling plant processes. The aflatoxin distribution among blanched lots differs from the aflatoxin distribution among rejected shelled lots before blanching because of the reduced aflatoxin concentration. The USDA chemically tests all blanched lots for aflatoxin. Usually all lots are accepted by the sampling plan due to the high efficiency of the blanching process at reducing aflatoxin to low or acceptable levels. Blanched lots are then shipped to manufacturers of consumer-ready products.

Results

To demonstrate how the market system model works, an example of a market system with specific aflatoxin regulations and industry processes was evaluated. Specific USDA sampling plans for FS and shelled peanut lots are defined and specific aflatoxin reductions due to shelling and blanching processes are also defined as outlined by the six market stages shown in Figure 1. A partial spreadsheet is shown in Table 3 that calculates the aflatoxin distribution among lots after each of the six stages in the market system. Where appropriate, the total number of lots and the average aflatoxin among all lots in the distribution are shown at the bottom of the spreadsheet in Table 3. Each stage is described below.

1. Farmer Stock Lot Distribution. It was decided to create a FS lot distribution where the average aflatoxin among all lots was 100 ppb. Using Equation 1, the standard deviation was calculated for a crop mean (M) of 100 ppb and the negative binomial distribution was used to calculate a aflatoxin distribution among FS lots as an input into the model. The FS lot distribution is shown in Figure 3 where the average aflatoxin among the 350,000 lots marketed by producers is 100 ppb. The choice of a FS lot distribution with an average of 100 ppb among all lots was arbitrary, but it represented a distribution that contains a substantial amount of aflatoxin that must be removed by market processes. Columns A and C in Table 3 also describe the FS lot distribution or the number of lots (column C) found at each unit for aflatoxin concentrations (column A) and defines the amount of aflatoxin coming into the market system. A more complete description of the FS lot distribution used in the model is shown in Figure 3. The FS lot distribution with only lots having concentrations up to 30 ppb are shown in Table 3 due the length of the FS lot distribution.

2. Proposed USDA FS Sampling Plan. An example of an OC curve describing a FS sampling plan that uses a 9.1-kg (20 lb) sample and a single tolerance of 100 ppb is shown in Figure 4 and tabulated in columns A (lot concentration) and B (accept probability) in Table 3. The sampling plan, described by the OC curve in Figure 4, has one tolerance (100 ppb) and partitions the 350,000 lots tested into two categories, accept and reject. The two new FS lot distributions for the accepted and rejected lots are shown in Figure 5 and in Table 3 by columns A,D and columns A,E, respectively. As Table 3 shows, of the 350,000 lots tested, 254,675 went into the accept category (accepted FS lot distribution) and 95,325 lots went into the reject category (rejected FS lot distribution). The average aflatoxin concentration among the accepted and rejected lots was 30.5 and 284.7 ppb, respectively. For this example, it is assumed that the rejected lots are crushed for oil and only the accepted lots are warehoused and processed for food use. The FS sampling plan removed 27.2% of the FS lots and reduced the aflatoxin from 100 ppb in all lots before testing to 30.5 ppb in the accepted lots. Other tolerances and sample sizes can be used to determine their effect on the accepted FS lot distribution.

3. Storage of Farmer Stock Peanuts. After the 350,000 FS lots are chemically tested for aflatoxin, it is assumed that the 254,675 accepted FS lots are commingled when placed into warehouses and the 95,325 rejected FS lots are crushed for oil. At this point in the market system (when the accepted FS lots are warehoused), the accepted FS lots lose their identity and the distribution among FS lots going into the warehouse changes due to commingling.

The 254,675 accepted FS lots are commingled on a 12 to 1 basis and the new commingled lot distribution is shown in Figure 6 and columns A and F in Table 3. The average aflatoxin among lots before and after commingling is 30.5 ppb. However, the number of lots at each aflatoxin concentration is drastically different. The lot distribution before and after commingling can be compared in Figure 6 and Columns D and F in Table 3. Commingling lots reduces the number of lots at both high and low aflatoxin concentrations. The new commingled lot distribution is not as wide as the accepted FS lot distribution before commingling.

4. Shelling Plant Processes. Equations 2 and 4 were used to change the commingled lot distribution that comes from the warehouse and into the shelling plant to the shelled lot distribution coming out of the shelling plant. The number of lots at each lot concentration (columns A and F in Table 3) did not change, but the aflatoxin concentration of commingled lots (column A) was reduced using Equation 2 (column G) to reflect shelling plant processes. In Table 3, columns G and F now describe the aflatoxin distribution among shelled lots after the shelling porcess. The average aflatoxin among the 21,194 commingled lots going into the shelling plants was 30.5 ppb and the average aflatoxin among the 21,194 shelled lots coming out of the shelling plant was 7.7ppb. The aflatoxin reduction in the shelling plant for this example was 74.8%.

The percentage aflatoxin reduction due to shelling

Table 3. Market system model spreadsheet for testing peanuts.

A	B	C	D	E	F	G	H	I	J	K	L
Lot conc.	PAC FS test OC Tolerance: < = 100	FS crop distribution M = 100 ppb	Accepted lots to storage	Rejected lots to oilstock	Lot distr. after storage 12/1 commingled	Lot conc. after shelling	PAC raw shelled test OC	Accepted lots to manufacturer	Rejected lots to blanch	Lot conc. after blanching	Blanched lots
ppb		no. lots	no.	no.	no.	ppb		no.	no.	ppb	no.
0	1.00000	50593.86	50593.86	0.00	0.01	0.00	1.00000	0.01	0.00	0.00	0.00
1	0.99828	17147.86	17118.37	29.49	0.56	1.00	1.00000	0.56	0.00	2.00	0.00
2	0.99659	11450.85	11411.80	39.05	3.12	1.52	0.99995	3.12	0.00	2.14	0.00
3	0.99486	8901.71	8855.96	45.75	9.16	1.94	0.99991	9.16	0.00	2.23	0.00
4	0.99309	7407.92	7356.73	51.19	19.72	2.30	0.99975	19.71	0.00	2.29	0.00
5	0.99126	6408.41	6352.40	56.01	35.47	2.64	0.99958	35.45	0.01	2.34	0.01
6	0.98938	5684.24	5623.88	60.37	56.69	2.94	0.99943	56.66	0.03	2.39	0.03
7	0.98745	5130.92	5066.53	64.39	83.36	3.23	0.99922	83.30	0.07	2.42	0.07
8	0.98546	4691.72	4623.50	68.22	115.15	3.50	0.99900	115.03	0.11	2.46	0.11
9	0.98341	4332.97	4261.08	71.88	151.48	3.75	0.99880	151.30	0.18	2.48	0.18
10	0.98131	4033.31	3957.93	75.38	191.62	4.00	0.99860	191.36	0.27	2.51	0.27
11	0.97914	3778.49	3699.67	78.82	234.70	4.24	0.99763	234.14	0.56	2.53	0.56
12	0.97692	3558.60	3476.47	82.13	279.75	4.46	0.99670	278.83	0.92	2.56	0.92
13	0.97464	3366.51	3281.13	85.37	325.80	4.68	0.99579	324.43	1.37	2.58	1.37
14	0.97230	3196.95	3108.39	88.56	371.86	4.90	0.99492	369.97	1.89	2.60	1.89
15	0.96990	3045.94	2954.26	91.68	416.98	5.11	0.99358	414.30	2.68	2.61	2.68
16	0.96745	2910.41	2815.68	94.73	460.30	5.31	0.99182	456.54	3.77	2.63	3.77
17	0.96493	2787.95	2690.18	97.77	501.05	5.51	0.99010	496.09	4.96	2.65	4.96
18	0.96235	2676.64	2575.86	100.78	538.53	5.70	0.98842	532.30	6.23	2.66	6.23
19	0.95972	2574.92	2471.20	103.72	572.21	5.89	0.98678	564.65	7.56	2.67	7.56
20	0.95703	2481.52	2374.89	106.63	601.65	6.07	0.98486	592.54	9.11	2.69	9.11
21	0.95428	2395.39	2285.87	109.52	626.53	6.25	0.98249	615.56	10.97	2.70	10.97
22	0.95147	2315.66	2203.28	112.38	646.66	6.43	0.98017	633.83	12.83	2.71	12.83
23	0.94861	2241.60	2126.40	115.20	661.95	6.60	0.97788	647.31	14.64	2.73	14.64
24	0.94569	2172.57	2054.58	117.99	672.42	6.78	0.97564	656.04	16.38	2.74	16.38
25	0.94271	2108.05	1987.28	120.77	678.18	6.94	0.97343	660.16	18.02	2.75	18.02
26	0.93968	2047.59	1924.08	123.51	679.41	7.11	0.97072	659.52	19.89	2.76	19.89
27	0.93659	1990.77	1864.54	126.23	676.35	7.27	0.96780	654.57	21.78	2.77	21.78
28	0.93344	1937.26	1808.32	128.94	669.31	7.43	0.96492	645.83	23.48	2.78	23.48
29	0.93024	1886.76	1755.14	131.62	658.63	7.59	0.96207	633.65	24.98	2.79	24.98
30	0.92699	1839.00	1704.74	134.27	644.68	7.75	0.95927	618.42	26.26	2.80	26.26
Total lots (no.)		350000	254325	95675	21194	21194		20130	1064		1064
Avg total aflatoxin (ppb)		100.0	30.5	284.7	30.5	7.7		7.6	9.4		2.9

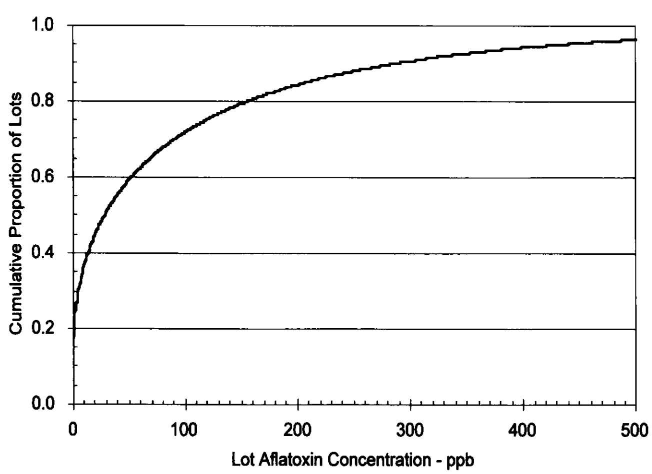

Fig. 3. Farmer stock (FS) crop distribution with 100 ppb average aflatoxin.

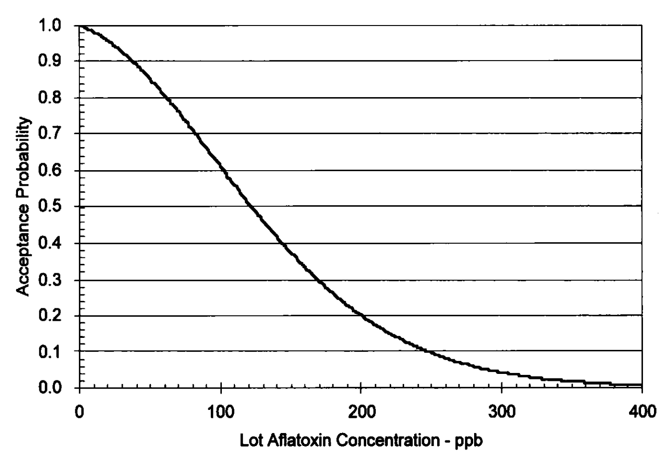

Fig. 4. Operating characteristic (OC) curve for the PAC FS testing plan; plan requires a 9.1-kg sample, vertical cutter mill, 200-g subsample, 1 aliquot, and immunoassay analysis.

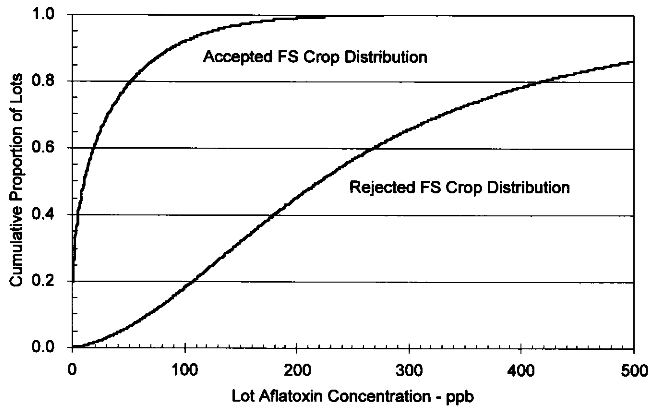

Fig. 5. Accept and reject crop distributions following the PAC FS test.

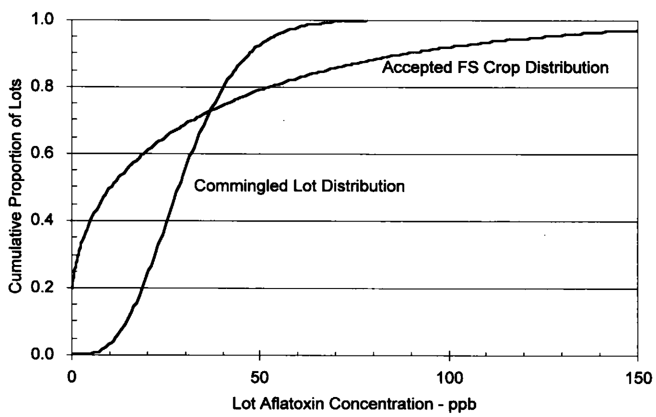

Fig. 6. Effect of commingling in storage on the PAC FS test accept crop distribution.

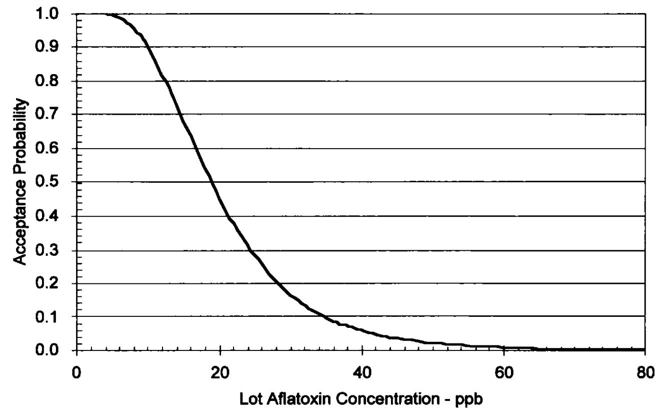

Fig. 7. Operating characteristic curve for PAC raw shelled testing plan; test requires up to three 22-kg samples, AMS mill, 1100-g subsample, 1 aliquot, and TLC analysis.

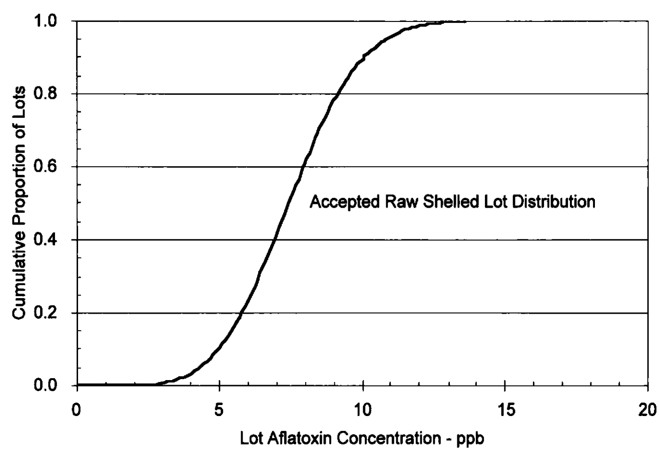

Fig. 8. Raw shelled lot distribution accepted by PAC and available for manufacture of consumer products or export market.

plant processes may vary for the market types and grades of peanuts. However, no information is available for grades other than medium runner peanuts. As a result, it is assumed that Equation 2 and 4 hold for all market types and grades of shelled lots. Studies need to be designed to measure the efficiency of shelling processes to reduce aflatoxin in farmer stock peanuts for various types and grades of peanuts.

5. USDA Sampling Plan for Shelled Peanuts. USDA samples and chemically tests shelled lots for aflatoxin before the lots are shipped to a manufacturer. The acceptance probabilities or OC curve for the USDA sampling plan is shown in Figure 7. The shelled lot distribution coming out of the shelling plant (21,194 lots described by columns F and G) is partitioned by the USDA sampling plan (columns G and H) into an accepted shelled lot distribution (20,130 lots described by column I) and into a rejected shelled lot distribution (1064 lots described by column J). The average aflatoxin among the accepted and rejected lots is 7.6 and 9.4 ppb, respectively. Accepted lots (Fig. 8) are shipped to a manufacturer or to an exporter. For this example, all rejected shelled lots are sent by USDA to a blanching facility to reduce the aflatoxin in each rejected lot. The USDA sampling plan for shelled lots rejects about 5.0% of the lots tested and reduces the aflatoxin from 7.7 ppb in all shelled lots tested to 7.6 ppb in shelled lots accepted. The aflatoxin reduction at this point in the market system is much less dramatic because most of the aflatoxin has been removed prior to this point.

6. Blanching Processes. USDA uses the blanching process to reclaim shelled lots rejected by the USDA sampling plan. The blanching process is a very effective method of reducing aflatoxin in shelled lots (11). Blanching is a two-step process where the skin is removed from the peanut kernel and the peanut kernels are passed through an electronic color sorter to remove discolored and damaged kernels from the lot. Color sorting after blanching is considered to be more efficient at detecting discoloration than color sorting in the shelling plant with the skin (reddish in color) intact.

The blanching process changed the aflatoxin distribution of shelled lots rejected by the USDA sampling plan. As in the shelling process, the number of lots in the rejected shelled lot distribution does not change (column L) but the aflatoxin in lots before blanching (column G) is reduced by Equation 5 and 6 and is shown in column K. The new blanched lot distribution is shown in columns K and L in Table 3. A plot of the rejected shelled lot distribution and the blanched lot distribution is shown in Figure 9. The average aflatoxin among rejected lots before and after blanching is 9.4 and 2.9 ppb, respectively. The aflatoxin reduction due to blanching is 69.1%.

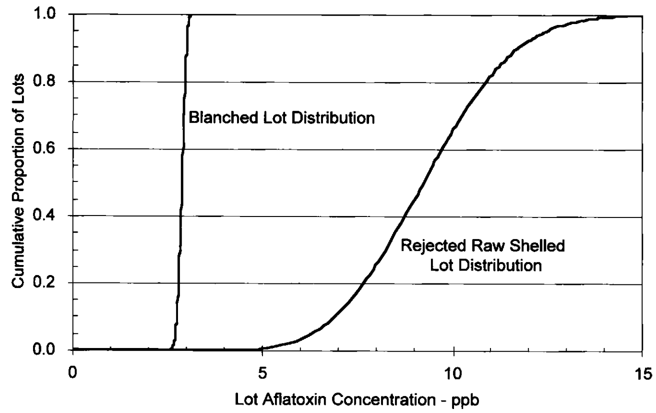

Fig. 9. Effect of blanching on reducing aflatoxin in the rejected raw shelled peanut lots.

The blanched lots are chemically tested by USDA to determine if the aflatoxin concentration of blanched lots is below the USDA tolerance. The blanching process is so efficient that with few exceptions all blanched lots pass the USDA aflatoxin test and are sent to manufacturers. As a result, the OC curve describing the USDA aflatoxin-sampling plan for blanched lots is not included in the model.

Model Summary. The spreadsheet in Table 3 shows in detail the distribution of lots according to their aflatoxin concentration after each step in the market system. With the exception of the FS sampling plan, the spreadsheet in Table 3 reflects current regulations and practices used by USDA and the U.S. peanut industry. A summary of the marking process and average aflatoxin among all lots after each market stage is given below and is shown in Table 4.

(a) Farmers market 350,000 lots with an average aflatoxin concentration of 100 ppb.

(b) The 350,000 FS lots are tested for aflatoxin using a 9.1-kg (20 lb) sample and 100 ppb threshold.

(c) Of the 350,000 lots chemically tested, 254,325 are accepted and 95,675 are rejected. The average aflatoxin concentration among the accepted and rejected lots is 30.5 and 284.7 ppb, respectively. The FS sampling plan rejected 27.3% of the lots and reduced the average aflatoxin among the accepted lots from 100 to 30.5 ppb. The FS chemical test removed about 69.5% of the aflatoxin from the crop.

(d) The accepted lots are commingled or combined in a warehouse. A total of 21,194 lots (each shelled lot represents 12 commingled farmer stock lots) are taken out of the warehouse and into the shelling plant. The average aflatoxin concentration among the 21,194 lots before shelling is 30.5 ppb, which is the same as the average aflatoxin concentration among the 254,325 accepted lots stored in the warehouse.

(e) The 21,194 FS lots coming out of storage are shelled and the average aflatoxin concentration among the 21,194 shelled lots has been reduced from 30.5 to 7.7 ppb. The shelling processes reduced the aflatoxin by 74.8%, which is the largest percent reduction of any process in the market system.

(f) The 21,194 shelled lots with an average aflatoxin concentration of 7.7 ppb are tested by USDA for aflatoxin. Of the 21,194-shelled lots tested by USDA, 20,130 lots are accepted and 1064 lots are rejected. The average aflatoxin among the accepted and rejected lots is 7.6 and 9.4 ppb, respectively. The accepted lots are sent to exporters and manufacturers.

(g) The 1064 shelled lots rejected by the USDA sampling plan are blanched. The average aflatoxin concentration among the blanched lots is 2.9 ppb. The blanching process reduced the aflatoxin in the rejected lots from 9.4 to 2.9 ppb, which is a 69.1% reduction in aflatoxin. The 20,130 accepted shelled lots, with an average aflatoxin concentration of 7.6 ppb, are sent to manufacturers and exporters.

The aflatoxin in FS lots was reduced form 100 to 7.6 ppb (excluding blanched lots) for a reduction of 92.4%. Chemical testing of FS lots, shelling plant processes, and blanching account for the greatest percentage reduction in aflatoxin.

Future Model Expansion. Currently, the final output of the market system model is the distribution of accepted shelled lots from the USDA sampling plan for shelled lots and the distribution of blanched lots from the blanching process. The model was developed originally to analyze only industry processes and aflatoxin regulations associated with the domestic market system. However, about 20% of U.S. peanuts are exported to foreign buyers. Collectively, European Union (EU) countries are the largest buyer of U.S. peanuts. As a result, the model is currently being expanded to predict the distribution of shelled lots in the export market and the effect of export sampling plans such as that currently being developed by the EU or by FAO/WHO through the CODEX process has on the removal of aflatoxin in the export market. Additional information is needed on the effects of shelling plant processes on the removal of aflatoxin from FS lots.

Summary and Conclusions

A spreadsheet model was developed that predicted the effects of USDA regulations and industry procedures and process on the reduction of aflatoxin in peanut lots. The model takes into account (a) the amount of aflatoxin contamination among lots marketed by farmers, (b) design of a FS sampling plan, (c) commingling of lots in the warehouse, (d) efficiency of shelling plant processes to reduce aflatoxin, (e) design of a sampling plan for shelled peanuts, and (f) efficiency of the blanching process to reduce aflatoxin in contaminated lots. Studies have provided information to describe the effects of USDA sampling plans for FS and shelled peanuts and reduction in aflatoxin due to blanching processes. However, information still is needed to describe the reduction in aflatoxin expected from shelling processes.

The model should provide USDA and the peanut industry with a method to predict the effects of new or different aflatoxin control strategies on aflatoxin reduction in peanut lots. As a result, various control strategies can be investigated with the model and the most cost-effective strategy can be determined and implemented by USDA and the peanut industry.

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