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Estimation of the Distribution of Lots of Shelled Peanuts According to Aflatoxin Concentrations[1]

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ABSTRACT

The distribution of shelled peanut lots according to their true aflatoxin concentrations is different than the distribution of aflatoxin assays made on those lots. This difference is due to assay errors associated with sampling, subsampling and analysis. A method was developed to estimate the distribution of the lots according to their true aflatoxin concentration based on aflatoxin assays. Estimates of the distribution of the 1973, 1974, and 1975 peanut lots were computed from their aflatoxin assays which were recorded by the Peanut Administrative Committee (PAC). Fifty-five percent of the PAC assays for the 3 crop years were less than 3 parts per billion (ppb) aflatoxin, whereas the estimated lot distribution indicated that only 48% of the lots were less than 3 ppb. On the other hand, only 94% of the assays compared to an estimated 96% of the lots were less than 25 ppb.

Key Words: Peanuts, Aflatoxin, Lot Distribution, Sample, Assay.

Approximately 25,000 commercial lots of shelled peanuts averaging over 30,000 kg per lot are produced in the United States each year. A U. S. Department of Agriculture Marketing Agreement administered by the Peanut Administrative Committee (PAC) requires that these peanuts be tested for aflatoxin contamination (1). The current PAC aflatoxin-testing program requires that all peanut lots used for edible purposes test 25 parts per billion (ppb) or less aflatoxin concentration. Since considerable economic loss is associated with those lots which fail to qualify for the edible market, the PAC needs to minimize the number of rejected lots which actually contain 25 ppb or less aflatoxin as well as the number of accepted lots which contain more than 25 ppb aflatoxin.

The distribution of accepted lots according to true aflatoxin concentration may be estimated with the following equation:

$$LA_M = TL \cdot F(M) \cdot P(M) \qquad (1)$$

where LA_M is the number of lots accepted with a true aflatoxin concentration M, TL is the total number of lots tested in a crop year, F(M) is the decimal fraction of the total number of lots tested at a given aflatoxin concentration M, and P(M) is the probability of accepting a lot with aflatoxin concentration M. The distribution of rejected lots according to true aflatoxin concentration may be estimated with the following equation:

$$LR_M = [TL \cdot F(M)] - LA_M \qquad (2)$$

where LR_M is the number of lots rejected with true aflatoxin concentration M.

Exact counts for TL for a given crop year are available from PAC records, and P(M) can be computed using Monte Carlo techniques described in a previous publication (2). The distribution of aflatoxin assays for a given crop year is also available from PAC records, but due to errors associated with sampling, subsampling and analysis (3), the distribution of these assays is not the same as the distribution of the lots according to their true aflatoxin concentration. Previous studies (4, 5) indicate that more than half of the samples taken from a lot will assay less than the true lot concentration and that a few will assay much higher. This skewness in the distribution of sample assays about the true lot concentration is mostly due to sampling error and is more pronounced when small samples are taken from the lot than when large samples are used. The lack of agreement between the distribution of assays and the distribution of lots according to their true aflatoxin concentration make it impossible to determine F(M) directly from PAC records.

The objective of this study was to develop a method to transform the distribution of PAC assays into a distribution of the lots according to their true aflatoxin concentration.

Methods

The lot distribution according to true aflatoxin concentration $L_o, \cdots, L_M, \cdots, L_j$ can be estimated by use of the system of equations:

$$\begin{aligned}
Y_o &= a^o_o L_o + a^o_1 L_1 + \cdots + a^o_M L_M + \cdots + a^o_j L_j \\
Y_1 &= a^1_o L_o + a^1_1 L_1 + \cdots + a^1_M L_M + \cdots + a^1_j L_j \\
&\vdots \\
Y_{\bar{x}} &= a^{\bar{x}}_o L_o + a^{\bar{x}}_1 L_1 + \cdots + a^{\bar{x}}_M L_M + \cdots + a^{\bar{x}}_j L_j \\
&\vdots \\
Y_i &= a^i_o L_o + a^i_1 L_1 + \cdots + a^i_M L_M + \cdots + a^i_j L_j
\end{aligned} \qquad (3)$$

where $Y_{\bar{x}}$ is the number of samples that assay $\bar{x}$ in ppb, L_M is the number of lots with concentration M in ppb, and $a^{\bar{x}}_M$ is the probability of obtaining an assay $\bar{x}$ from a lot with concen-

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tration M. Values for $Y_{\bar{x}}$ were determined from a record of the first official PAC assay made on each lot tested. The probability coefficients $a_M^{\bar{x}}$ were estimated from the negative binomial probability function

$$a_M^{\bar{x}} = f(N\bar{x}) = \frac{\Gamma(N\bar{x}+NK)}{N\bar{x}!\,\Gamma(NK)} \left(\frac{NK}{NM+NK}\right)^K \left(\frac{NM}{NM+NK}\right)^{N\bar{x}} \qquad (4)$$

where $\bar{x}$ is the assay, N is the sample size, M is the lot concentration, K is a constant, and Γ is the gamma function. The parameter M is assigned, whereas the parameter K is obtained from variance relationships determined in a previous study (3).

Trial and error techniques were used to solve Equation 3. We substituted different trial lot distributions into Equation 3 for $L_O, \cdots, L_M, \cdots, L_j$, and obtained different predicted assay distributions $\hat{Y}_O, \cdots, \hat{Y}_{\bar{x}}, \cdots, \hat{Y}_j$, which were then compared with the PAC assay distribution $Y_O, \cdots, Y_{\bar{x}}, \cdots Y_i$. The sum of squares of the deviations between the predicted and the PAC assay distributions (SSQ) were computed.

$$SSQ = \sum_{\bar{x}=o}^{i} (\hat{Y}_{\bar{x}} - Y_{\bar{x}})^2 \qquad (5)$$

The trial lot distribution that minimized SSQ was accepted as the true distribution of lots L_O, • • •, L_M, • • •, L_j from which the PAC assays had been otained.

The trial lot distributions substituted into Equation 3 were generated with Equations 6 and 7.

$$L_M = TL \bullet F(M), \qquad (6)$$

where TL is the total number of lots tested in that crop year and F(M) is the decimal fraction of TL with aflatoxin concentration M. We assumed that F(M) could be described by the negative binomial probability function (6).

$$F(M) = \frac{\Gamma(M+k)}{M!\,\Gamma(k)} \left(\frac{k}{\mu+k}\right)^k \left(\frac{\mu}{\mu+k}\right)^M \qquad (7)$$

where M is the lot aflatoxin concentration, μ is the average aflatoxin concentration in all lots tested in a given crop year, Γ is the gamma function, and k is a constant. The value of μ was set equal to the average of all PAC assays for the crop year. We generated different trial lot distributions by varying the parameter k in Equation 7.

Results

The cumulative distributions of lots according to estimated true aflatoxin concentration, of PAC assays, and of predicted assays for the 1973, 1974, and 1975 crops are shown in Figures 1, 2, and 3, respectively. According to PAC assays the average aflatoxin concentration in all lots tested in 1973, 1974, and 1975 was 9.4, 5.2, and 6.0 ppb, respectively. For each of the above crop years, the negative binomial constant k that minimized SSQ was 0.9028, 0.7380, and 0.5234, respectively. Since the sensitivity of the PAC analytical procedure is about 3 ppb, SSQ was computed for predicted assays and PAC assays greater than 3 ppb.

A comparison of the curves in Figures 1, 2, and 3 shows that at low aflatoxin concentration the cumulative frequency of PAC assays is higher than the estimated frequency of lots and that the situation is reversed at higher concentrations. Fifty-five percent of the PAC assays for the 3 crop years were less than 3 ppb aflatoxin, whereas the estimated lot distribution indicated that only 48% of the lots were less than 3 ppb. On the other hand, only 94% of the assays compared to an estimated 96% of the lots were less than 25 ppb aflatoxin. The large

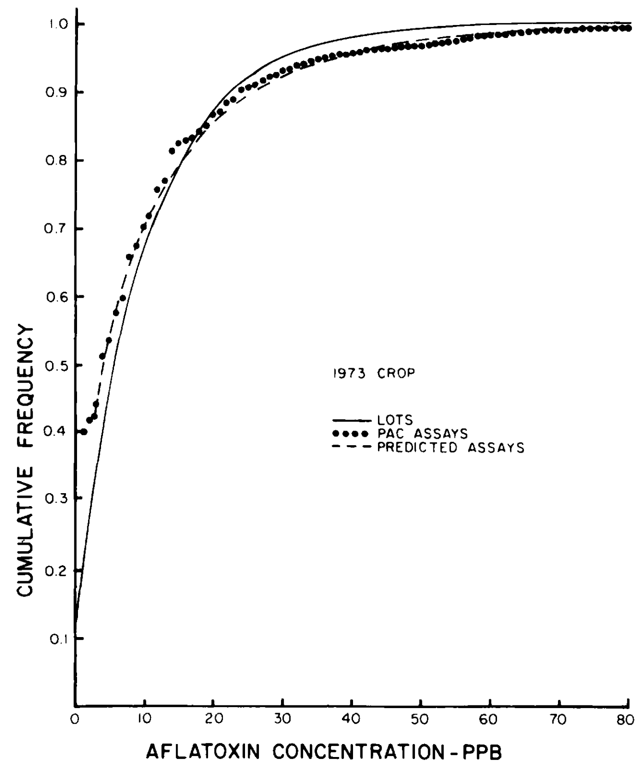

Fig. 1. Cumulative distributions of lots according to estimated true aflatoxin concentrations, of PAC assays, and of predicted assays for the 1973 crop. The parameters used in Equation 4 were: k = -.9028, μ = 9.4 ppb.

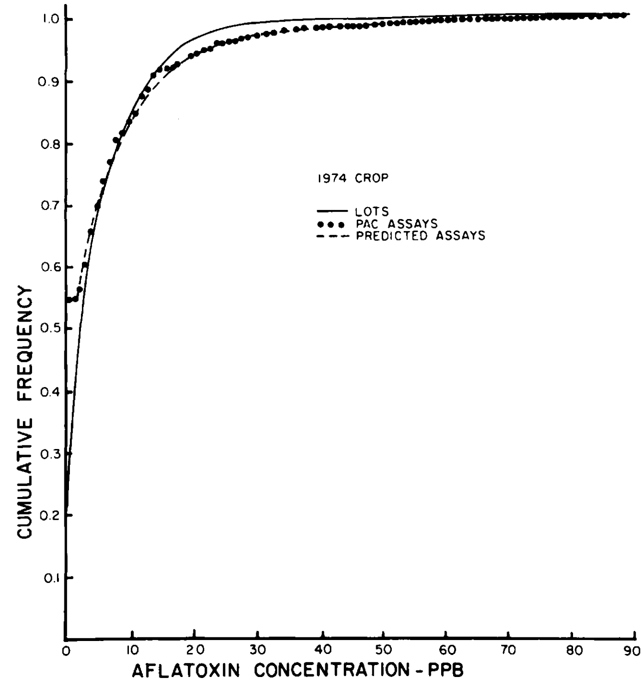

Fig. 2 Cumulative distributions of lots according to estimated true aflatoxin concentrations, of PAC assays, and of predicted assays for the 1974 crop. The parameters used in Equation 4 were: k = 0.7380, μ = 5.2 ppb.

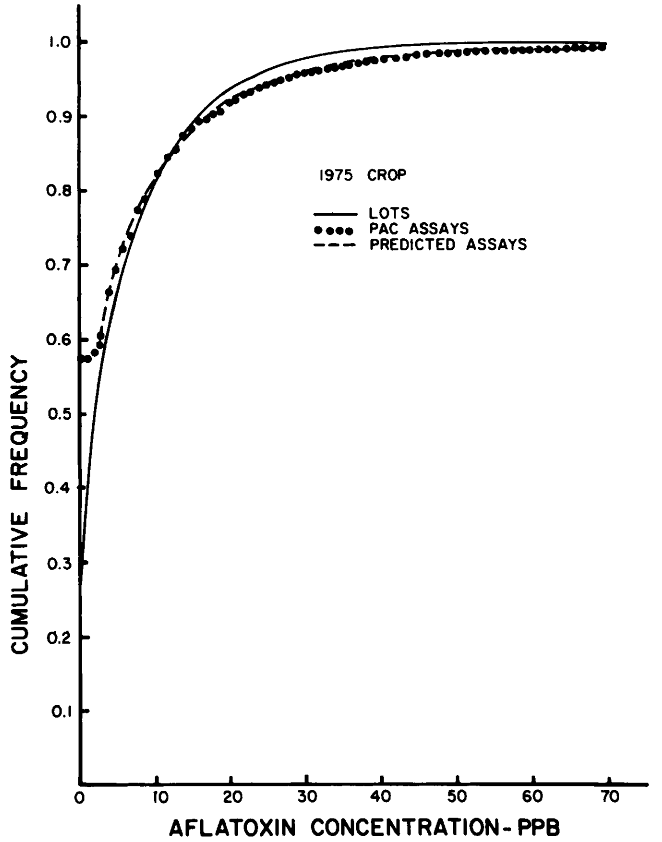

Fig. 3. Cumulative distributions of lots according to estimated true aflatoxin concentrations, of PAC assays, and of predicted assays for the 1975 crop. The parameters used in Equation 4 were: k = 0.5234, μ = 6.0 ppb.

difference in the two distributions below 3 ppb is probably mainly due to the 3 ppb detection limit of the PAC assay method.

For each crop year the PAC assay distribution changes abruptly at about 15 ppb. This was one of the critical values used in the aflatoxin testing program when the assays were made, because lots that assayed 15 ppb or less were accepted without further testing; so the deviation may indicate a bias toward acceptance for assays near this value (1).

If application of the relationship expressed by Equation 7 and the probability coefficient $a_{M}^{\bar{x}}$ are correct, the distribution of PAC assays for crop years 1973, 1974, and 1975 have been transformed into lot distributions that more nearly reflect the true aflatoxin concentrations of the lots produced in those years. Differences between the distribution of PAC assays and the estimated distribution of lots indicate the errors that are inherent in survey studies when the distribution of sample assays is equated with distribution of lots according to true aflatoxin concentrations.

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