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An Empirical Model for Estimating Weight Loss of Stored Cowpea Seeds

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Abstract: This paper presents statistical analyses in developing an empirical model, which relates the weight of cowpea remaining after insect infestation to number of the insect pest (*Callosobruchus maculatus*), time and the initial weight of the cowpea. The data consist of weekly measurements of the weight of cowpea remaining in each experimental plastic pot for eleven weeks. To four pots each containing 50g of seeds at 13 % moisture content (wet basis) were introduced 0, 5, 10 and 15 insects. There were three replicates. Using the least square theory, the unknown parameters were efficiently estimated. In addition, residual graphs were used to show the appropriateness and adequacy of the model. The analyses showed that the model closely predicts the results of the actual experiments. The model can be used to estimate the weight loss of cowpea due to the insect pest (*Callosobruchus maculatus*) infestation during storage.

Key words: Empirical model, weight loss, cowpea, *Callosobruchus maculatus*

Introduction

The food and economic damage of cowpea (*Vigna unguiculata*) by insect pest (*Callosobruchus maculatus*) has been reported by Caswell (1970; 1981) and Riley (1965). The eggs of the insect are attached to the surface of the seeds. The larvae bore into the seeds and feed within the cavity, which they make. They pupate within the cavity and the adults make emergence holes when they emerge. The damage through the insect infestation results in the loss in weight of the stored cowpea seeds. One method of estimating loss in weight is to determine the amount of cowpea in storage and so calculate the loss that the total amount has suffered in weeks or months. In cowpea storage, the insect causes most of the loss with rodents and mould contributing to the total loss.(Caswell, 1981). Caswell (1981) estimated the loss in weight of stored cowpea by first converting the level of damage to the number of emergence holes per cowpea seed. He further converted the number of emergence holes into weight loss by assuming a 10% weight loss of cowpea per hole. The two regression equations for converting the level of damage to the number of emergence holes per cowpea seed were:

1. $y = 2.7997x - 0.0514x^2 + 0.0006x^3 \quad (r^2 = 0.988)$

   where:

   y = number of emergence holes

   x = level of damage from 7% to 89%

2. $y = 1.8077x \quad (r^2 = 0.991)$

   where

   y = number of emergence holes

   x = level of damage up to 50% damage

This work was to develop an empirical model to estimate weight loss of cowpea seeds due to insect pest (*C. maculatus*) infestation during storage. The interest in studying the weight loss arises from the following considerations. Weight loss in stored cowpea is a major primary damage in cowpea, which has caused a great deal of possible concern in Nigeria resulting in considerable food and economic loss. There is no information on weight loss in the south eastern zone of Nigeria. The study may thus serve as a useful method to estimate the weight loss of cowpea stored over a given time period.

Materials and Methods

Test Insects: Cowpea seeds infested with cowpea bruchids (*C. maculatus*) were bought from the local market and sieved to remove all adult insects. The seeds were stored in a perforated container for one week under laboratory condition (28 ± 1 °C) for the further emergence of the adult insects. The newly emerged insects (about 1-4 days old) were used for the experiment.

Cowpea Seeds: Clean cowpea seeds bought from the local market in Calabar were stored at between 0 - 2°C for seven days to ensure that all stages of the insect were completely destroyed. Seeds without emergence holes and undamaged were selected for the experiment. The seeds were dried in an air-oven (28 ± 1 °C) for 24 hours to a moisture content of 13% (wet basis)

Procedure: The experiment was carried out in a laboratory at room temperature. 50 g of the seeds were put in four carefully weighed plastic pots and covered with fine screen. To each of the pots were introduced 0, 5, 10 and 15 insects respectively. There were three replicates. The weights of the cowpea remaining in the pots after the infestation by the insects were measured at weekly intervals for eleven weeks. The cowpea seed powder was thoroughly shaken out from each pot and the weight of each pot recorded at the end of each week. The weight of the cowpea remaining in the pot was obtained by subtracting the weight of the plastic pot.

Data Analysis: The data in Table 1 consists of weekly measurements of the weight of cowpea remaining in each pot after infestation by the insect pest (*C. maculatus*). Fig. 1 presents graphs of the average weight of cowpea remaining (grams) versus time in weeks for 0, 5, 10 and 15 insects respectively. The graphs show that the weight of cowpea remaining decreased approximately exponentially with time. Also the weight decreased with increase in the number of insects.

The analysis of variance (ANOVA) showed significant differences among the mean values associated with the different number of insect and time period. It is believed that from the data obtained, the variations in the weight of cowpea remaining after infestation may be due to the following factors:

1. the number of insects
2. the time period of cowpea exposure to insect infestation
3. the initial weight of the cowpea.

An Empirical Model: The weight of cowpea remaining might be expected to decrease exponentially with the number of insects S, and the time in weeks T, yielding a relationship

$$M = f(M_o, S, T, \text{and unknown constants})$$

Where f( ) denotes 'a function of'

Using the following notations:

M_o = initial weight of cowpea

M = measured weight of cowpea remaining

S = number of insects in each pot

T = time in weeks

θ_1 & θ_2 = parameters

Thus more appropriately we may write an empirical model in the form

$$M = \theta_1 M_o \exp(-\theta_2 \times S \times T / M_o) \qquad (1)$$

The model is not linear in the parameters θ_1 and θ_2 (Box and Lucas, 1959), however a model, linear in the parameters can be obtained by taking the logarithms of equation (1), as follows:

$$M/M_o = \theta_1 \exp(-\theta_2 \times S \times T/M_o) \qquad (2)$$

$$\log_e(M/M_o) = \log_e\theta_1 - (\theta_2 \times S \times T/M_o) \qquad (3)$$

Let

$y_n = \log_e(M/M_o)$

$\alpha = \log_e\theta_1$

$\beta = -\theta_2$

$x_n = S \times T/M_o$

Table 1: Weight of Cowpea Remaining (grams) and Number of Insects with Time (Three replicates)

No. of Insects	Time (Weeks)											
	0	1	2	3	4	5	6	7	8	9	10	11
	50	49.98	49.97	49.96	49.95	49.93	49.92	49.91	49.9	49.88	49.86	49.84
0	-	49.99	49.98	49.97	49.95	49.94	49.93	49.92	49.9	49.88	49.80	49.77
	-	-	-	49.98	49.96	49.95	49.94	49.93	49.9	49.88	49.74	49.71
	-	48.45	46.3	44.1	42.63	41.9	40.99	40.89	39.8	39.0	37.3	37.1
5	-	49.14	47.45	45.1	44.18	43.0	42.0	40.67	37.49	36.1	34.7	33.5
	-	49.83	48.6	48.1	47.1	45.02	41.3	40.45	35.3	33.1	30.3	29.8
	-	47.8	43.3	42.7	40.1	40.0	39.4	38.4	37.1	35.1	35.5	33.1
10	-	48.0	45.45	42.48	41.8	41.0	39.8	38.5	35.7	32.8	32.0	31.0
	-	48.93	47.6	43.3	43.3	41.93	40.11	39.1	34.21	31.1	30.10	29.5
	-	45.5	41.1	40.1	40.0	39.1	37.1	36.4	34.5	33.0	31.0	30.0
15	-	44.4	43.01	41.23	40.6	40.50	39.3	34.3	30.0	28.0	19.6	14.8
	-	44.9	41.5	41.0	40.2	39.50	38.0	35.4	32.5	30.0	25.5	23.1

Hence, equation(1) is finally transformed into the form

$y_n = \alpha + \beta x_n + \epsilon_n$ (4)

Where

y_n = value of the n^{th} output variable,

x_n = value of the n^{th} input variable,

ϵ_n is an error term and α and β are unknown parameters.

The parameters θ_1 and θ_2 can now be efficiently estimated using standard least squares techniques (Box *et al.*, 1978 and Larson, 1974). The errors ϵ_n are supposed to be IIDN(0,σ^2), that is, independently and identically distributed according to a normal distribution with zero mean and unknown but fixed variance, σ^2. This condition must hold for the linear regression to apply (Box *et al.*, 1978)..

Results and Discussion

Plot of the Least Squares Line: The best fitting straight line was obtained by the least squares method by determining the values of the parameters α and β, that minimize the sum of squares of the errors S_e,

$S_e = \sum (y_n - y_n^*)^2$ for n = 1, 2 3, ...131

Where y_n^* are the predicted output values from the fitted equation.

The values of - 0.02481 and – 0.19877 in Table 2 are the least squares estimates of α and β, respectively.

Hence α^* = -0.02481 and β^* = - 0.19877.

A plot of the fitted equation

$y_n^* = - 0.02481 - 0.19877 x_n$ (5)

and the experimental data are presented in Fig. 2.

Analysis of Residuals: The least squares estimates of α and β, are used to calculate the predicted values

$y_n^* = \alpha^* + \beta^* x_n$ for n = 1, 2, 3 131

Consequently, the residuals or estimated errors are found as

$\epsilon_n^* = y_n - y_n^*$

Discrepancies between a model and the experimental data can be detected by studying the residuals. These residuals are the quantities remaining after the systematic contributions associated with the equation are removed. Plots of residuals against input variables x_n, and predicted vales y_n^* are presented in Fig. 3 and 4 respectively. The points were found to be adequately scattered, evenly distributed above and below the 0.00 line, showing white noise. This further showed that the residuals were unrelated to the input variables and predicted values .The model is found to be appropriate and therefore explains the data.

Table 2: Summary of the regression analysis

Regression	*Statistics*
Multiple R	0.924738
R Square	0.85514
Adjusted R Square	0.854017
Standard Error	0.073732
Observations	131

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.139921	4.139921	761.5122	5.76E-56
Residual	129	0.701302	0.005436		
Total	130	4.841223			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.02481	0.009174	-2.70438	0.007767	-0.04296	-0.00666	-0.04296	-0.00666X
Variable 1	-0.19877	0.007203	-27.5955	5.76E-56	-0.21302	-0.18452	-0.21302	-0.18452

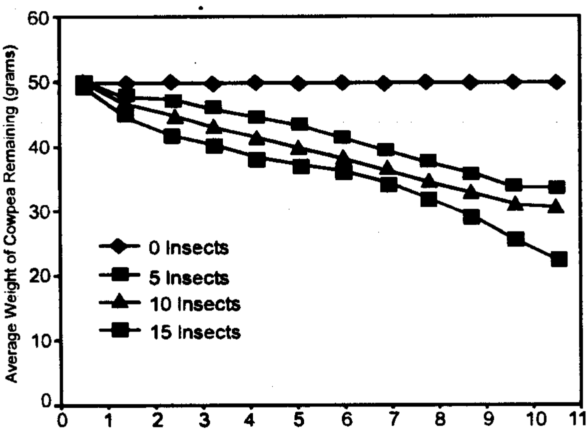

Fig. 1: Average weight of cowpea remaining (grams) versus time (weeks) for 0,5, 10 and 15 Insects respectively

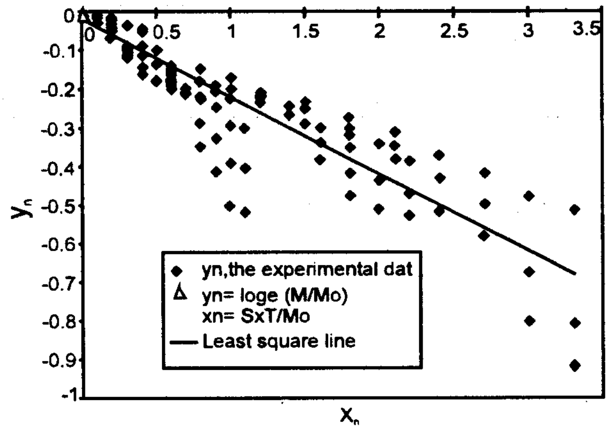

Fig. 2: Line-fit plot

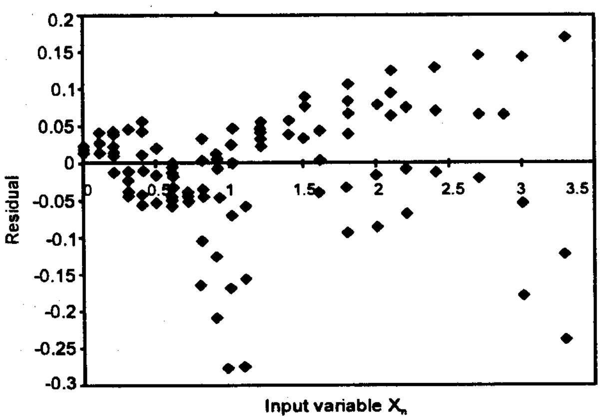

Fig. 3: Graph of Residual versus Input Variable (X_n)

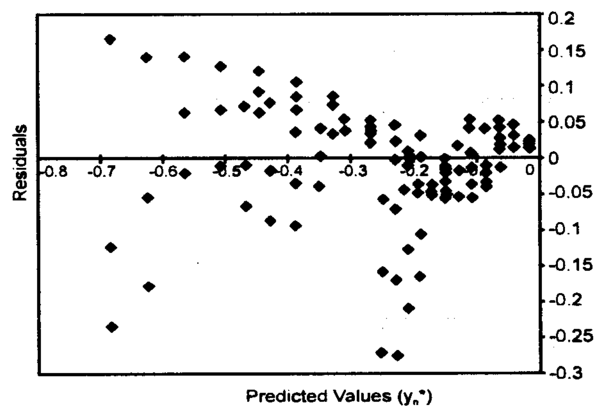

Fig. 4: Graph of Residual versus Predicted Variable (y_n*)

Estimation of σ^2: The method of least squares does not contain any rationale for estimating σ^2. However on the assumption that the model is adequate, the mean sum of squares of the errors s_e^2, presents an unbiased estimator for σ^2 (Larson, 1974), where

$$s_e^2 = [\sum \epsilon_n^{*2} / n-2]$$

An estimate of the error variance σ^2 is

$$s_e^2 = 0.701302/ (131-2) = 0.7013\ 02/129 = 0.005436$$

Thus, the estimated standard deviation for the transformed data of the experiment is $= (0.005436)^{1/2} = 0.07373$

Determination of parameters θ_1 and θ_2

The estimates of the parameters θ_1 and θ_2 are

$$\theta_1^* = e^{\alpha^*} = e^{(-0.02481)} = 0.9755 \quad (6)$$

$$\theta_2^* = -\beta^* = -0.19877 \quad (7)$$

Thus the fitted empirical model is

$$M = 0.9755\ M_0 \exp\{[-0.19877 \times S \times T] / M_0\} \quad (8)$$

($r^2 = 0.85514$)

Test of Adequacy of the Model

The statistical model (equation (4)) is said to be adequate if a set of parameters α and β exists such that

$$f(y_n, x_n, \alpha, \beta) = \epsilon_n$$

where ϵ_n is white noise, that is IIDN($0,\sigma^2$) and is unrelated to any known variable. The model therefore should be capable of transforming informative data to informationless white noise. Hence, considering equation (4)

$$y_n = \alpha + \beta x_n + \epsilon_n$$
$$\log_e(M/M_o) = \log_e\theta_1 - \theta_2 \times S \times T/M_o + \epsilon_n$$
$$= \log_e\theta_1 + \epsilon_n - \theta_2 \times S \times T/M_o$$
$$\log_e(M/M_o) = \log_e\theta_1 + [M_o\epsilon_n - \theta_2 \times S \times T] / M_o$$

that is

$$M/M_o = \theta_1 \exp\{[M_o\epsilon_n - \theta_2 \times S \times T] / M_o\}$$

Therefore

$$M = \theta_1 M_o \exp\{[M_o\epsilon_n - \theta_2 \times S \times T] / M_o\} \quad (9)$$

When $T = 0$

$$M = \theta_1 M_o \exp(\epsilon_1) \quad \text{where } n=1 \quad (10)$$

$\theta_1^* = 0.9755$

$\epsilon_1 = 0.024811$

Given that $M_o = 50g$

Substituting into equation (10),

$$M = 0.9755(50)\exp(0.024811)g$$
$$= 0.9755(50)(1.025)g$$
$$= 50 \text{ g}$$

The calculated value of M at T = 0 is consistent with the observed value, showing that the transformation has succeeded. The developed empirical model (equation (8)) is efficient and contains within itself all the information in the data.

Conclusion

An empirical model had been chosen over a theoretical or mechanistic model because the mechanism underlying the process of insect infestation of cowpea seeds is not understood well to allow an exact model to be postulated from theory. The model so developed relates the weight of cowpea at 13% moisture content remaining after infestation to different numbers of the insect, time and the initial weight of the cowpea. The model may be useful, particularly since it is desired to approximate the output only over limited ranges of the variables considered in this work.

The statistical analyses show that the model closely predicts the results of the actual experiments. The model therefore can be used to estimate the weight loss of cowpea due to insect pest (*Callosobruchus maculatus*) infestation during storage.

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