鋼皮及水泥圓筒倉用於儲存進口玉米之研究

A Study of Storing Imported Corn in Steel and Concrete Bins

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摘　　要

在臺灣高溫高濕的氣候下，探討鋼皮和水泥圓筒倉用於儲藏進口玉米之可行性。本文內容包括儲藏玉米之溫濕度，發芽率，脂肪酸度，昆蟲數與微生物在 100 噸鋼皮圓筒倉和 600 噸水泥圓筒倉在 3.5 個月內變化的情形。並且推演一可預測玉米生熱之數學模式並證明在貯藏期內確有生熱之現象，為移除產生之熱量，在儲藏期間給予通風並追踪通風之影響。

在平均氣溫介於 12.5°C和 25.5°C之間，平均相對濕度介於64%和88%之間，在53天之儲藏之後，在鋼皮倉內 14.9%含水率之玉米溫度高達 41°C，而在臨近水泥圓筒倉內14.7%含水率之玉米溫度最高溫度38°C發生在第63天之儲藏。

經過 116.7 小時之間歇通風，在鋼皮圓筒倉之下、中、上層玉米含水率之減低率各為 1.9%、1.7% 和 1.8% 。而經過146小時之間歇通風，在水泥圓筒倉之下、中、上層之玉米含水率之減低率各為 1.4%、 0.8% 和 2.4%。

經過 3.5 個月之儲藏，在鋼皮或水泥圓筒倉中心之發芽率各降至 0 %或13%。

經過 3.5 個月之儲藏，玉米受到曲黴菌感染率在鋼皮或水泥圓筒倉各為從 47.5 %增至98.3%，或從76.1%增至87.8%。

經過 3.5 個月之儲藏，玉米受到青黴菌感染率在鋼皮或水泥圓筒倉各為從 67.5 %減為 22.8%，或從 41.7%增為 86.7%。

適量之應用好達勝殺蟲劑，在剛開始儲藏48天內可有效地控制昆蟲之繁殖。

以 50 公絲苛性鉀／100 公克乾玉米為允許脂肪酸度，在鋼皮或水泥圓筒倉之儲藏期限各為49天或67天。

Abstract

Under the hot and humid climate in Taiwan, the feasibility of adapting steel and concrete tanks for storing imported corn was studied. This paper includes changes of temperature, moisture content, viability, fatty acid value, insect and microorganism count of corn stored in a 100-ton steel tank and in a 600-ton concrete silo during 3.5-month storage. In addition, a mathematical model was also developed to predict corn heating and applied to prove the existing heating during the storage. To remove the generated heat, aeration was applied and its effect was detected by the following check-up.

Under the average ambient air temperatures between 12.5°C and 25.5°C and average relative humidity between 64% and 88%, the maximum temperature of corn with 14.9% moisture content in the steel tank was 41°C after 53-day storage. However, the maximum temperature of corn with 14.7% moisture content in the nearby concrete silo was 38°C after 63-day storage.

After the intermittent aeration for 116.7 hours, the reduction of corn moisture content was 1.9%, 1.7% and 1.8% respectively at the bottom, middle and top layers of steel tank. After the intermittent aeration for 146 hours, the reduction of corn moisture content was 1.4%, 0.8% and 2.4% respectively at the bottom, middle and top layers of concrete silo.

After 3.5-month storage, the viability of corn near the center of steel or concrete bin was dropped down to 0% or 13% respectively.

The amount of corn infested by Aspergillus was increased from 47.5% to 98.3% in steel tank or from 76.1% to 87.8% in concrete silo after 3.5-month storage.

After 3.5-month storage, the amount of corn infested by Penicillium was from 67.5% down to 22.8% in the steel tank or from 41.7% up to 86.7% in the concrete silo.

By properly applying insecticide, Phostoxin, it may be very effective to control the development of insects during the first 48 days of storage.

Basing on the allowable fatty acid value of 50 mg KOH/100g dry corn, the allowable storage time was 49 days in the steel tank or 67 days in the concrete silo.

INTRODUCTION

To meet the need of feed industries, we imported 2,960,148 metric tons of corn n 1984 mainly from the U.S. (Feed Grain and Livestock Production 145, 1985). To keep constant supply, the government people require minimum amount of corn in stock is the capacity enough for 3-month processing. Therefore, the storage of imported corn becomes very important to maintain good quality of feeds.

Because the local construction cost of a 1000-metric-ton steel tank is only about half of the concrete silo (Shaw and Chen, 1985), the feasibility of storing imported corn in steel tanks is enquired by local steel tank manufacturers and feed manufacturers. Although steel tanks are extensively used to store grain under the temperate climate, there is lack of information under the hot and humid climate such as the subtropic weather in Taiwan.

To investigate the storability of corn by measuring the change of corn temperature, moisture, viability, fatty acid content, insect and microorganism count during the storage, an experimental 100-metric-ton steel tank was constructed to store the imported corn from the U.S. These results were also compared with the corn stored in a 600-metric-ton concrete silo nearby.

These experimental results could be used by local steel tank manufacturers and feed manufacturers to determine the feasibility of storing imported corn in economic steel tanks in subtropic areas such as Taiwan.

LITERATURE REVIEW

Effect of Temperature, Moisture and Mechanical Damage

Maximum storage life of corn could be estimated as a function of moisture content, temperature and mechanical damage by the following equation (Muir, 1973; Shaw, 1985).

$$S = S_R \times M_T \times M_M \times M_D \quad \cdots\cdots (1)$$

where

S = estimated maximum storage time for a loss of 0.5% dry matter, h

S_R = time for corn having 25% moisture content (W.B.), and 30% mechanical damage, stored at 15.6°C to lose 0.5% dry matter
= 230 h

M_T = temperature multiplier, dimensionless

M_M = moisture multiplier, dimensionless

M_D = mechanical damage multiplier, dimensionless

The temperature multiplier (M_T) could be expressed by the following equation if temperature is greater than 15.6°C and moisture content is between 19% and 28% (Steele, 1967):

$$M_T = 32.3\ e^{-3.48(T/15.6)} + \frac{(M-19)}{100}\ e^{0.61((T-15.6)/15.6)} \quad \text{......(2)}$$

where

T = temperature, °C
M = moisture content, % (W.B.)

As shown in Figure 1, the moisture multiplier (M_M) could be seen directly from the graph if the moisture content is between 15% and 35%.

Basing on 0.5% dry matter loss, the mechanical damage multiplier (M_D) for corn could be expressed by the following equation (Steel, 1967):

$$M_D = 2.08\ e^{-0.0239D} \quad \text{......(3)}$$

where

D = mechanical damage, %

Assuming the harvested corn in the U.S. with 30% mechanical damage, 15% moisture content, storage temperature 25°C, the estimated storage time would be about 18.4 days if the extrapolation of Equation (2) is allowable. In Taiwan, the average monthly temperature in June, July, August and September would be around 30°C. If substituting T is equal to 30°C into Equation (2), the temperature multiplier (M_T) would show a negative value.

In Taiwan, the moisture content of imported U.S. corn was about 15% (Liao et. al.,1983). Under 30°C storage temperature, the imported U.S. corn would be subjected to insect heating, loss of viability, damp grain heating and mite attack as shown in Figure 2 (Hyde and Burrell, 1973).

Because of most of grain tanks in Taiwan without grain spreaders, the broken kernels and foreign material could form a tightly packed spoutline around the bin center as shown in Figure 3 and develop hot spots (Liao et. al., 1983).

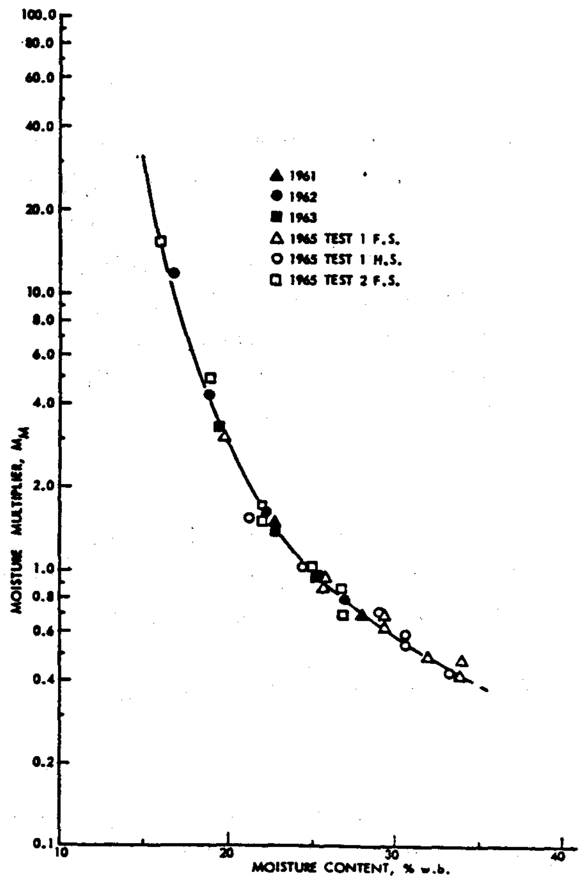


Figure 1. Moisture content multiplier for corn (Steele, 1967).

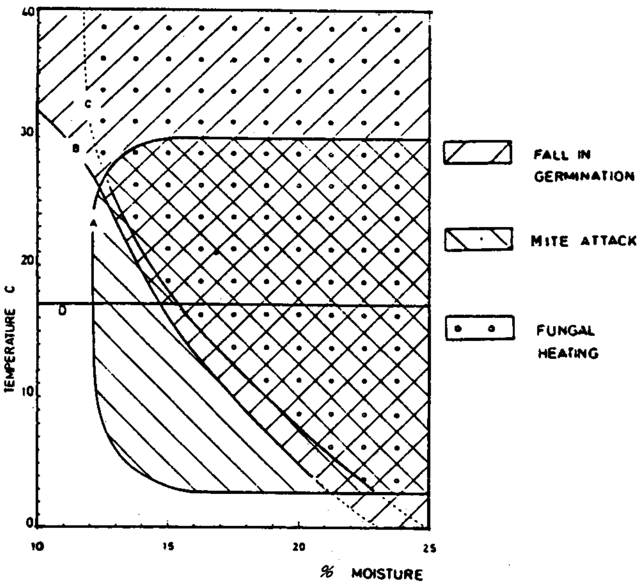


Figure 2. Effect of grain moisture content and temperature on insect heating (above line D), fall in germination to 95% in 35-week storage (line B), damp grain heating (to the right of line C) and mite attack (shaded area within line A) (Hyde and Burrell, 1973).

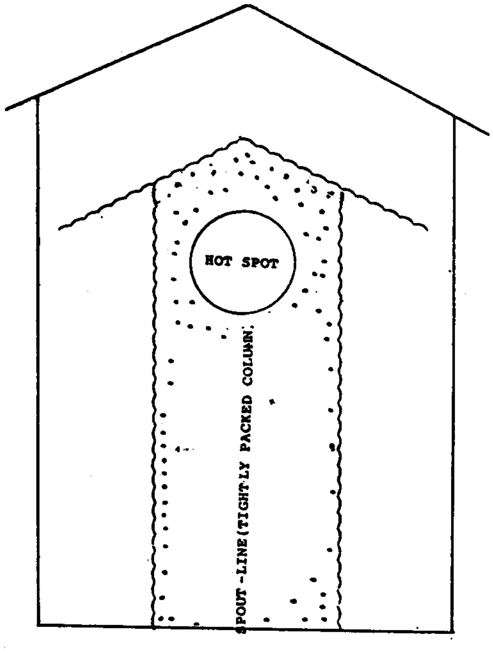


Figure 3. Schematic diagram of spoutline of loading grains into tanks and the location of possible developing hot spot (Liao et. al., 1983).

Due to a long handling path of imported corn, the broken kernels and foreign material could become double the original amount (Liao et. al., 1983). Consequently, it may need higher airflow rate and more time to cool the hot spot by aeration.

Effect on Free Fatty Acid Content

Among the intermediate products of spoilage in materials that contain fats or oils are free fatty acids which have a characteristic rancid odor and flavor. Milner et. al. (1947) stated that "Increased fat acidity and loss of germination accompany mold growth. On the other hand, where mold growth was virtually inhibited (nitrogen atmosphere), fat acidity and germination remained essentially constant, in spite of the elevated moisture value used in this trial."

Christensen et. al. (1949) working with cottonseed stated: "In general, the increase in mold population of the stored seeds was correlated closely with increased production of carbon dioxide and free fatty acids." The amount of fatty acids produced varied with the species of fungus (Goodman and Christensen, 1952). Cracked and broken kernels of corn may increase greatly in fatty acid value without being invaded by fungi (Christensen and Kaufmann, 1969).

High fatty acid values unquestionably indicate some deterioration either biological or purely chemical, but deterioration may occur without any significant increase in fatty acid value (Christensen and Kaufmann, 1969).

According to Chen (1977), fatty acid values below 50 mg KOH per 100 g dry corn would be considered as allowable safe storage for corn.

Development of Temperature Prediction Equations in a Grain Bin

To design and evaluate methods of reducing the temperature in grain bins, it is necessary to predict the temperatures in grain bins. Two methods to predict temperature in a cylindrical model bin are shown. The first is an analytical solution in which a one-dimensional transient heat flow with a uniform initial temperature, a constant ambient temperature, and a constant heat generation rate is presented. A comparison of the results of this equation is made with that of a finite difference equation. The reason for this comparison is to assist in the selection of suitable time and space increment for the finite difference equation and to validate the finite difference procedure for temperature prediction. Since a cylindrical bin is one of the common shapes of steel and concrete bins, the analytical and finite difference method for temperature prediction is developed in the cylindrical coordinate system.

Consider an infinite cylinder of radius R at a uniform temperature T_o placed into an infinite medium where the temperature T_a is different from T_o. Heat transfer between the cylindrical surface and medium is assumed to follow Newton's law. Inside the cylinder there is a uniform heat source, which has a constant strength W. The temperature distribution along the radius of the cylinder at any time is to be found. According to Luikov (1968, page 371), the following equations apply:

$$\frac{\partial T(r,t)}{\partial t} = a\left(\frac{\partial^2 T(r,t)}{\partial r^2} + \frac{\partial T(r,t)}{r\partial r}\right) + \frac{W}{c\gamma} \quad (t > 0, 0 < r < R) \; \ldots\ldots (4)$$

$$T(r,0) = T_o \quad \text{(initial condition)} \; \ldots\ldots (5)$$

$$\frac{\partial T(0,t)}{\partial r} = 0 \; ; \; T(0,t) \neq \infty \quad \text{(boundary condition)} \; \ldots\ldots (6)$$

$$\frac{-\partial T(R,t)}{\partial r} + H(T_a - T(R,t)) = 0 \quad \text{(boundary condition)} \; \ldots\ldots (7)$$

Where T = Temperature, °C
t = time, h
a = diffusivity, m^2/h
H = ratio of convective heat transfer coefficient to conductivity, 1/m
r = radial distance, m
R = radius of cylinder, m
W = generated heat, J/m^3-h
c = specific heat, J/kg–°C
γ = density, kg/m^3
T_o = initial cylinder temperature, °C
T_a = medium temperature, °C

The solution of Equation (4) is (Luikov 1968, page 371):

$$T(r, t) - T_o = \frac{W}{c\gamma} t + (T_a - T_o)(1 - \sum_{n=1}^{\infty} A_n J_o (u_n \frac{r}{R}) e^{-u_n^2 F_o})$$
$$- \frac{WR^2}{c\gamma a} (F_o - \frac{1}{4} (1 + \frac{2}{B_o} - \frac{r^2}{R^2})$$
$$+ \sum_{n=1}^{\infty} \frac{A_n}{u_n^2} J_o (u_n \frac{r}{R}) \cdot e^{-u_n^2 F_o}) \qquad (8)$$

Where $J_o (u_n \frac{r}{R})$ = Bessel function of the first kind, order zero.

P_o = $\frac{WR^2}{k(T_a - T_o)}$, Pomerantsev number, dimensionless.

k = thermal conductivity, J/h-m-°C

F_o = $\frac{at}{R^2}$, Fourier number, dimensionless.

h = convective heat-transfer coefficient, $J/h\text{-}m^2\text{-}°C$.

B_o = $\frac{R \cdot h}{k}$, Biot number, dimensionless.

A_n, B_n = constants.

u_n = roots of the characteristic equation.

Substituting r equal to zero in Equation (8), the temperature along the cylinder axis, T_c, is found:

$$T_c = T(0,t) = T_o + (T_a - T_o)\,(1 + \frac{P_o}{4}\,(1 + \frac{2}{B_o})$$
$$- \sum_{n=1}^{\infty} (1 + \frac{P_o}{u_n^2})\,A_n\, e^{-u_n^2 F_o}) \quad \ldots\ldots\ldots\ldots (9)$$

Where $$A_n = \frac{2B_o}{J_o(u_n)\,(u_n^2 + B_o^2)} \quad \ldots\ldots\ldots\ldots (10)$$

u_n, the roots of the characteristic equation, can be found by the following Equation (11):

$$\frac{J_o(u)}{J_1(u)} = \frac{u}{B_o} \quad \ldots\ldots\ldots\ldots (11)$$

Where $J_o(u)$ = Bessel function of the first kind, order zero.
$J_1(u)$ = Bessel function of the first kind, order 1.
B_o = Biot number.

The intersections of $J_o(u)/J_1(u)$ and u/B_o give the roots u_n (Luikov 1968, page 267).

The above analytical solution is based on an initially uniform bin temperature, constant boundary temperature and constant internal heat generation rate. However, under high moisture and temperature, corn will respire and produce heat. Therefore a numerical solution based on the following assumptions was developed:

(1) Heat transfer by conduction in the vertical direction and by natural convection in the bin are negligible.

(2) The heat flow is entirely in the radial direction.

(3) The distribution of temperature, T, is symmetrical about the cylindrical axis.

(4) The internal heat, W, generated by biological and/or non-biological agents is constant and uniform, in a finite period, Δt, but may vary with a function of temperature or time.

Consider the sector of a cylindrical bin shown in Figure 4 which has an angle of $\Delta\theta$ and a thickness of Δz. The arcs halfway between the reference points are taken as defining the width of heat-flow path and also the volumes of the respective regions (Dusinberre, 1961; Muir, 1970; Yaciuk et. al., 1975). The sector is divided into finite spatial elements of equal radial width, $\Delta r/2$.

The heat balance equation for an interior spatial element i is:

heat flow in + heat generation = heat flow out + heat stored ...... (12)

Mathematically this may be expressed as:

$$k\,(i\Delta r - \frac{\Delta r}{2})\,(\Delta\theta)\,(\Delta z)\,(\frac{T_{i-1} - T_i}{\Delta r})\,(\Delta t) + (i\Delta r\Delta\theta)$$

$$(\Delta r)\,(\Delta z)\,(W\Delta t) = k(\ i\Delta r + \frac{\Delta r}{2})\,(\Delta\theta)\,(\Delta z)\,(\frac{T_i - T_{i+1}}{\Delta r})\,(\Delta t)$$

$$+ (i\Delta r\Delta\theta)\,(\Delta r)\,(\Delta z)\,(\gamma c)\,(T_i' - T_i) \quad \ldots\ldots\ldots\ldots (13)$$

Where

- k = thermal conductivity, J/h-m-°C (572.9 J/hr-m-C° for corn)
- Δr = length of radius increment, m
- i = number of spatial increment
- Δz = depth of sector, m
- $\Delta\theta$ = angle of bin sector, rad.
- W = generated heat, J/m³-h
- Δt = finite time period, h
- T_{i-1} = temperature of elements i-1 at time t, °C
- T_i = temperature of element i at time t, °C
- T_{i+1} = temperature of element i+1 at time t, °C
- T_i' = temperature of element i at time t + Δt, °C
- γ = density, kg/m³ (718 kg/m³ for corn)
- c = specific heat, J/kg-°C (2027.4 J/kg–°C for corn)

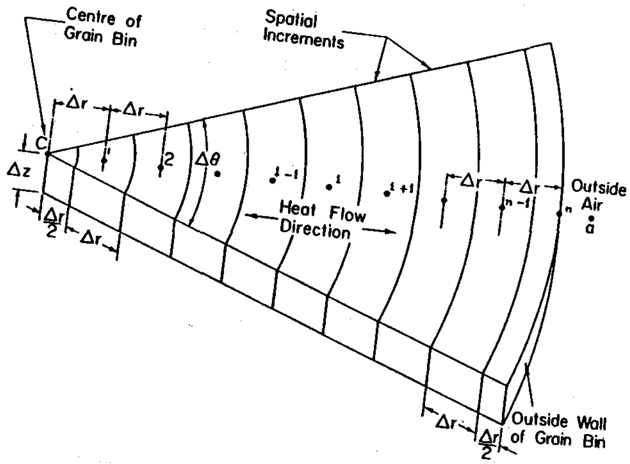


Figure 4. A sector of the grain bin.

Equation (13) can be simplified by defining a dimensionless modulus M,

$$M = \frac{c\gamma\,(\Delta r)^2}{k\Delta t} \quad \ldots\ldots\ldots\ldots (14)$$

$$T_i' = (1 - \frac{2}{M})\,T_i + \frac{2i-1}{2\,(M)\,(i)}\,T_{i-1} + \frac{2i+1}{2\,(M)\,(i)}\,T_{i+1} + \frac{(W)\,(\Delta t)}{(\gamma)\,(c)} \quad \ldots\ldots (15)$$

From assumption (3), the heat balance equation of the center element, c, with no heat flow across the center axis is:

$$(\frac{0 + (\frac{\Delta r}{2})\,(\Delta\theta)}{2})\,(\frac{\Delta r}{2})\,(\Delta z)\,(W)\,(\Delta t) = (\frac{\Delta r\Delta\theta}{4})\,(\frac{\Delta r}{2})\,(\Delta z)\,(\gamma c)\,(T_c' - T_c)$$

$$+ k\,(\frac{\Delta r\Delta\theta}{2})\,(\Delta z)\,(\frac{T_c - T_1}{\Delta r})\,(\Delta t) \quad \ldots\ldots\ldots\ldots (16)$$

Equation (16) can be simplified as:

$$T_c' = \frac{(W)(\Delta t)}{(\gamma)(c)} + (1 - \frac{4}{M}) T_c + \frac{4}{M} (T_1) \qquad (17)$$

The heat balance equation for the exterior spatial element n is:

$$k (n\Delta r - \Delta r/2)(\Delta\theta)(\Delta z)(\frac{T_{n-1} - T_n}{\Delta r})(\Delta t) + (W)$$

$$(\frac{(n\Delta r) + (n\Delta r - \frac{\Delta r}{2})}{2})(\Delta\theta)(\frac{\Delta r}{2})(\Delta z)(\Delta t)$$

$$= h (n\Delta r\Delta\theta)(\Delta z)(T_n - T_a)(\Delta t) + (\frac{(n\Delta r) + (n\Delta r - \frac{\Delta r}{2})}{2})$$

$$(\Delta\theta)(\frac{\Delta r}{2})(\Delta z)(T_n' - T_n)(\gamma)(c) \qquad (18)$$

Where

h = convective heat-transfer coefficient, J/h-m² -C°(122,652 J/h-m² – C° for the predicted temperature calculation).

Substitute $h (\Delta r)/k = B_o$ (Biot number) into Equation (18) and rearrange:

$$T_n' = \frac{(8n-4)}{(4n-1) M} T_{n-1} + \frac{8 (B_o)(n)}{(4n-1) M} T_a + (1 - \frac{8n-4 + 8B_o n}{(4n-1) M}) T_n + \frac{(W)(\Delta t)}{(\gamma)(c)} \qquad (19)$$

Where T_n' is the surface temperature at time $t + \Delta t$.

To choose a proper M, the center-line temperature calculated from the analytical solution, Equation (9), is used as a standard solution to compare with the numerical solution for temperatures from Equations (15) and (17) until both temperatures have acceptable agreement. To obtain stable solutions, it is necessary to choose suitable time and space increments so that the coefficients of Equations (15), (17), and (19) are greater than zero (Dusinberre, 1961; Shaw, 1977).

EXPERIMENTAL PROCEDURES

As shown in Figure 5, an experimental steel tank, 5.32m diameter by 6.096m eave height, was set up at Hsiaokong Feed Mill. Temperature cables 1, 3, 4, and 6 were used to measure the grain temperature inside the tank. Cable 5 went around the outside tank shell with 4 measuring points facing to the north, south, west and the east. Cable 2 was used to dectect the inlet and outlet air temperatures of aeration system. These temperature readings were recorded by Foss Thermo-scan Universal Desk Top Read-out Unit.

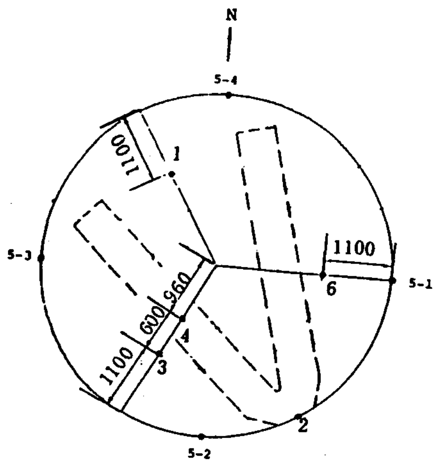
The humidity of air inlet and outlet of aeration system was measured by Vaisala Humicap probe and recorded by Sekonic SS-100 P Recorder.

Every two weeks, 1.5kg samples around the temperature cables 1, 3, 4 and 6 and near the bin center were taken by Probe-A-Vac Pneumatic Grain Sampler to analyze the change of moisture content, viability, fatty acid content, and micro-organisms. Every 4 weeks, the change of insect count was also analyzed besides the above items.

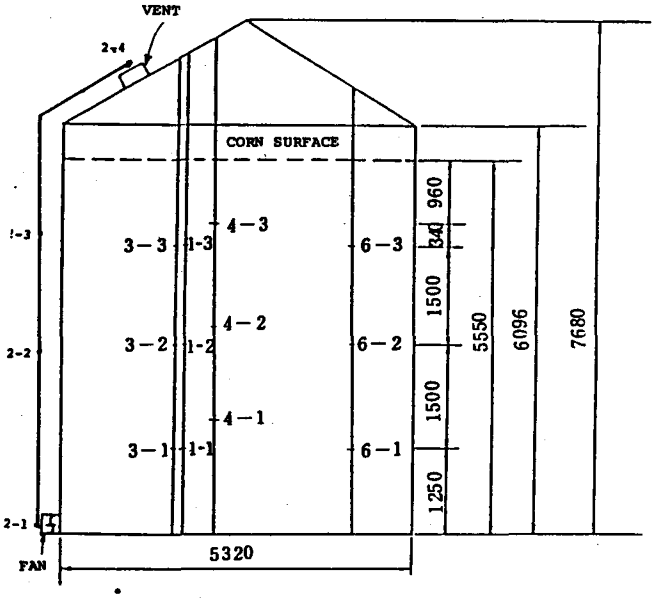
The change of moisture content was measured by AOAC (1980) air oven method. Grind sample to pass No. 20 sieve, weigh about 2g sample, dry in 130±3°C oven for 1h, transfer to desiccator, weigh soon after reaching room temperature, and report the percentage of moisture content on a wet basis.

The germination measurement was done by placing 100 intact kernels on moist paper in a perforated plastic tray storing in a 30°C temperature control chamber, and then recording the number of germinated seeds after 4 days.

About 10g of corn were pulverized in a Microject-10J grinder to pass No. 20 sieve. The oil of ground corn meal was extracted with n-hexane for 30 minutes in a beaker by constant stirring. After filtration, extraction was repeated once. Corn oil was obtained by removing n-hexane from filtrate with an evaporator. Acid value of corn oil was determined as the method described by Chang (1983).



(a) TOP VIEW



(b) SIDE VIEW

Figure 5. Locations of temperature measurement of the experimental steel tank.

About 39g Potato Dextrose Agar was mixed with 1ℓ of distilled water and 1cc NPX (a type of detergent), heated to 121°C for 20 minutes, and then added 50% of Lactic acid solution until the medium with a 3.8 PH value. Four corn kernels in each plate were placed in the above PDA medium, kept in 25°C chamber, and then inspected the colonies between 5 and 7 days.

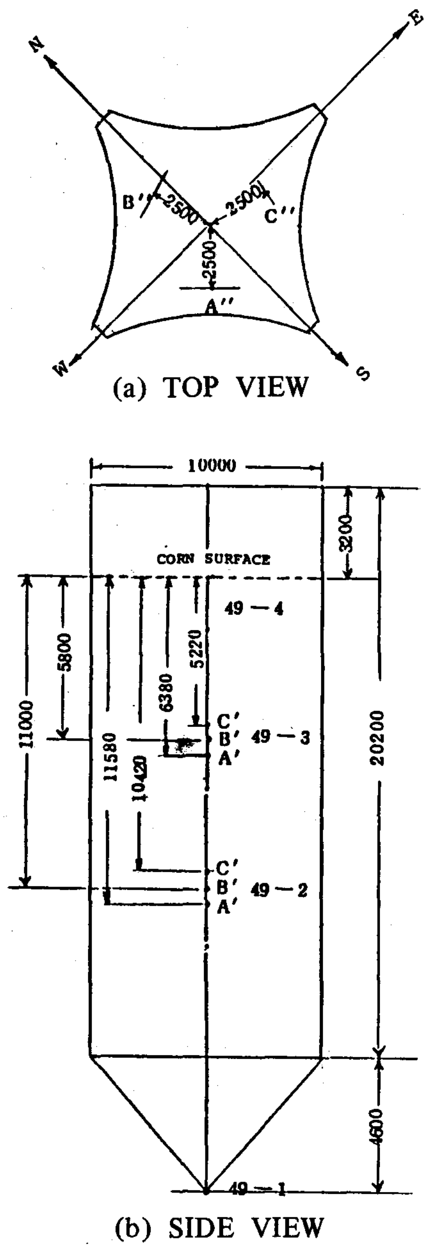
Only part of 1ℓ of corn samples passed No. 16 sieve was used to investigate the amount of live and dead insects. The last sample was sieved, placed in the room temperature for one month, and then sieved again to inspect the amount of larva.

As shown in Figure 6, a 600 metric ton concrete silo at Hsiaokong Feed Mill was used to store the imported corn which was unloaded from the same ship as that stored in the steel tank. The same procedures were applied to analyze these samples to see the change of temperature, moisture content, viability, fatty acid value, insect and microorganism count.

RESULTS AND DISCUSSIONS

As shown in Figure 7, the average outside temperature even in the winter and spring seasons remained between 12.5°C and 25.5°C, but the highest temperature recorded 29°C. The average relative humidity even in the dry season was between 64 and 88% as shown in Figure 8.

Under the above ambient air conditions, the stored corn temperature daily recorded at 4 P.M. was shown in Figure 9 and Figure 10. As shown in Figures 7, 9 and 10, the initial corn temperature was about 4°C higher than the ambient, but remained very constant in the beginning of 31-day storage. Then the corn temperature was gradually increasing to 32°C and 41°C respectively at measured points, 3-3 and 4-3 after 53-day storage. The predicted temperature as shown in Figure 11 was based on the developed Equations (15), (17) and (19) by neglecting item W. The measured temperature as shown in Figure 11 was the average temperature of measured points, 4-1, 4-2, and 4-3. Since the predicted model is assumed no heat generation within the grain bulk, the variation between the measured and the



Notes: (1) B'', C'' and A'' are located 250cm from the bin center on the corn surface.

(2) C' and A' are located above or below point B' about 58cm.

Figure 6. Locations of sampling of the 600-metric-ton concrete silo.

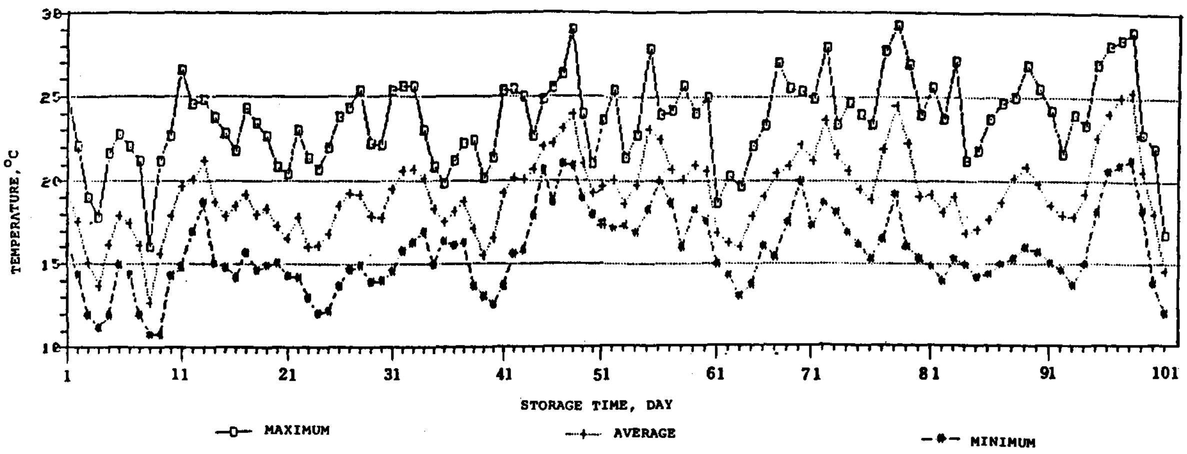


Figure 7. The outside air temperature from December 21, 1984 to March 29, 1985.

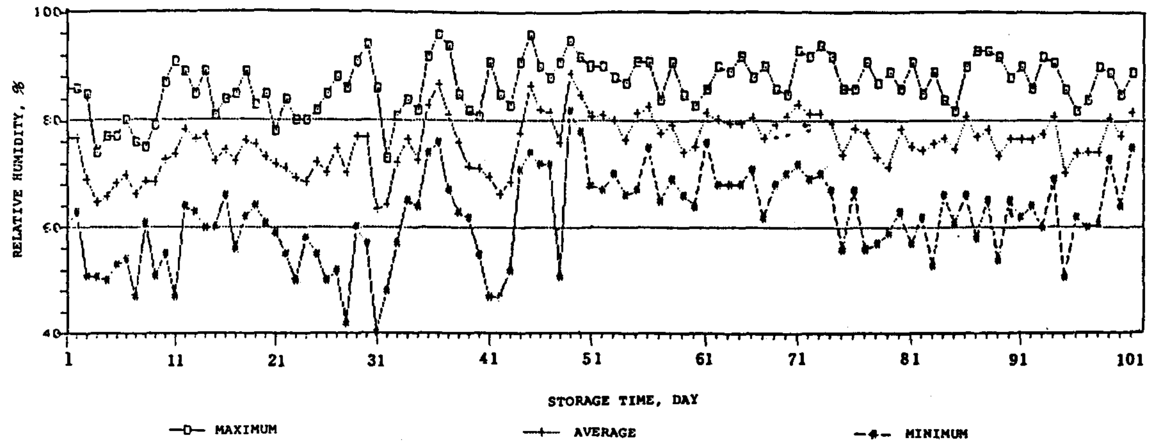


Figure 8. The relative humidity of outside air from December 21, 1984 to March 29, 1985.

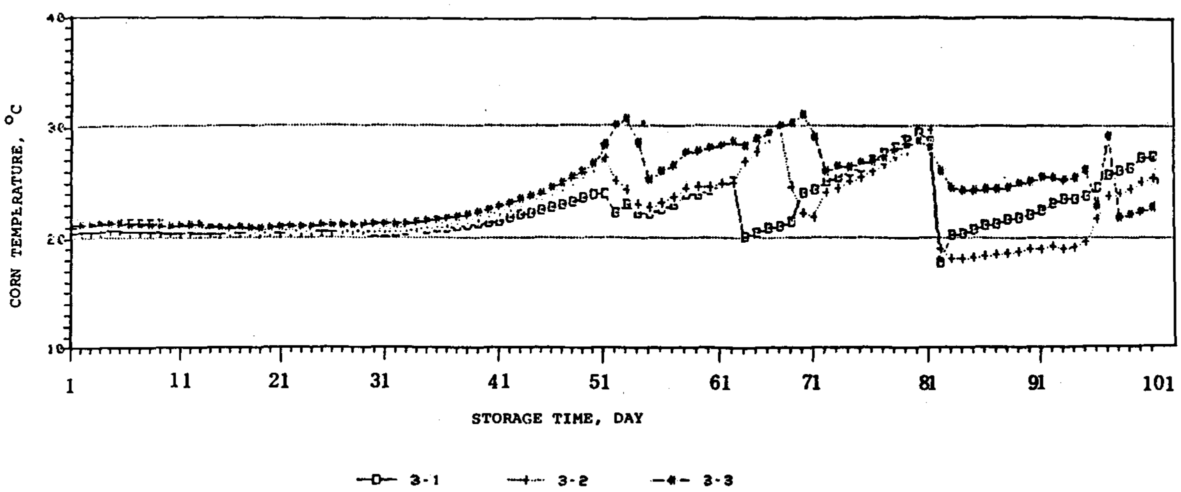


Figure 9. Corn temperatures measured daily at 4 p.m. by cable 3 at three different locations from December 21, 1984 to March 29, 1985.

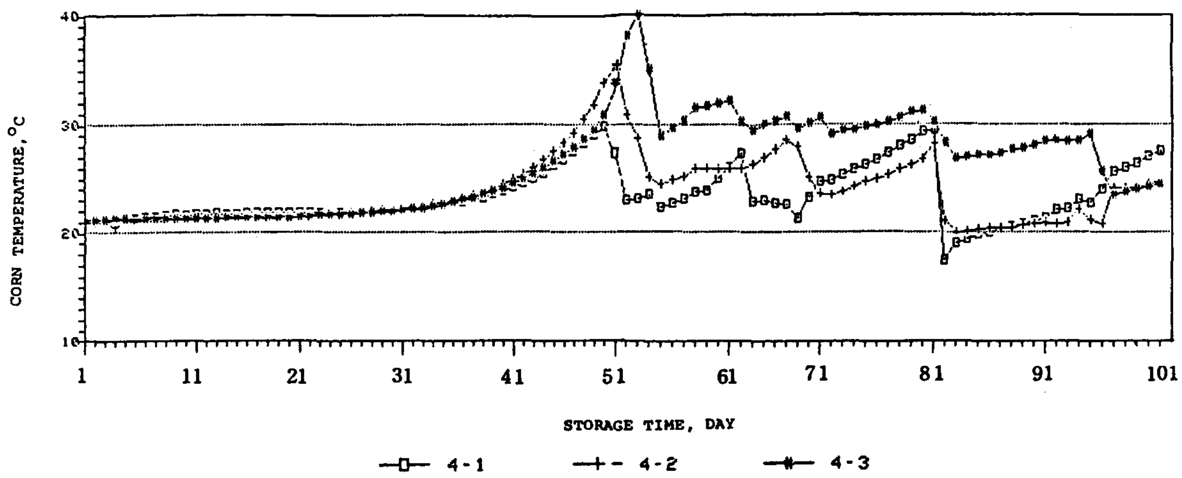


Figure 10. Corn temperatures measured daily at 4 p.m. by cable 4 at three different locations from December 21, 1984 to March 29, 1985.

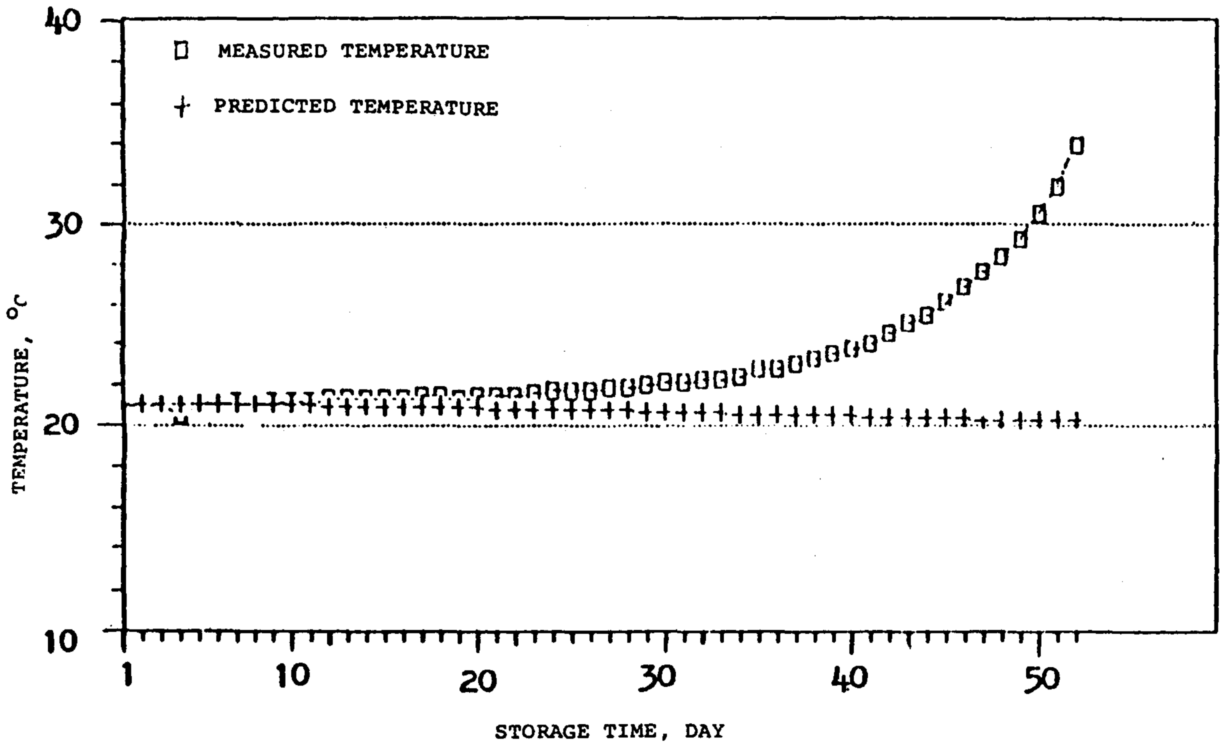


Figure 11. Predicted and measured temperatures 101cm from the steel bin center at 4 p.m. daily from December 21, 1984 to February 10, 1985.

predicted may be used to validate the existing hot spots due to biological activities, and the generated heat, W, increased as storage time.

To reduce the hot spots, a one-horsepower fan with an air flow rate of 0.327m^3/min./metric-ton was used to aerate the steel tank. The total aeration time as shown in Table 1 was 116 hours and 41 minutes. Basing on the ambient air conditions and aeration duration, the location of maximum temperature may remain the same or change. As shown in Figures 12, 13 and 14, the variation between the measured and the predicted temperature may be due to the existing hot spots as moving heat sources after aeration (Ding, 1985).

As shown in Figure 15, the change of relative humidity of air outlet was dependent on the relative humidity of inlet air and the duration of aeration. After 11-hour aeration, the relative humidity remained 100% for 9 hours. Consequently, it may result in some condensation on the steel tank roof. According to the relative humidity of inlet air, it was very favorable for aeration with low night humidity and temperature to remove hot spots.

The initial moisture content of corn was 14.9% (W.B.). After 3.5-month storage, the change of moisture content of corn at three different layers was shown in Figure 16. Mainly due to the aeration effect, the reduction of moisture content of corn was 1.8%, 1.7% and 1.9% respectively at the top, middle and bottom layers of steel bin.

As shown in Table 2, the germination of corn decreased with storage time at the bottom, middle and top layers. For example, the viability of corn at the top layer dropped from 45% in the beginning (December 20, 1984) down to 9% at the end of storage (April 3, 1985). With initial 45% of germinated seed, Table 3 showed germination decreased with storage time at different cable locations as shown in Figure 5 and the center (7) of steel tank. Near the center of tank, rapid decrease in viability may indicate appreciable damage to seed due to higher temperature. After 2.5-month storage, the germination around the center of tank approached to zero as shown in Table 3.

As shown in Figure 17, fatty acid value near the center of steel tank was varied with the storage time. After 2.5-month storage, the fatty acid value reached the peak, 79mg KOH/100g dry corn or 20mg KOH/g corn oil from the initial value, 21mg KOH/100g dry corn or 5.8mg KOH/g corn oil. In general, the fatty acid value for safe storage would be about 50mg KOH/100g dry corn (Chen, 1977). Therefore, the safe storage time would be about 49 days.

As shown in Figure 18, corn infested by Aspergillus reached the peak, 100%, from the initial rate, 47.5%, after 66-day storage. On the other hand, the infested rate by Penicillium reached the peak, 100%, only after 19-day storage from the initial rate, 67.5%. This result may explain Aspergillus could be one of sources causing hot spots.

As shown in Figure 19, corn infested by Fusarium from the initial infested rate, 47.5%, dropped down to zero after February 25, and then kept the same value. Figure 19 also showed the infested rate by Mucor increased to 50-70% from the initial infested rate, 7.5%, after March 11.

Table 1. Aeration record of steel tank in 1985

No.	Beginning of aeration				Maximum temperature before aeration		Maximum temperature during aeration		End of aeration				Maximum temperature after aeration		Aeration duration	
	month	day	hour	min	location	°C	location	°C	month	day	hour	min	location	°C	hour	min
1	02	11	13	15	4 - 2	35.9	4 - 2	36.3	02	11	18	56	4 - 2	35	5	41
2	02	12	10	00	4 - 2	35.8	4 - 3	38.5	02	12	19	00	4 - 3	38	9	0
3	02	14	09	00	4 - 3	41.3	4 - 3	38.5	02	14	22	10	4 - 3	30.9	13	10
4	02	15	09	00	4 - 3	32.8	2 - 3 5 - 3	31.3	02	15	13	00	2 - 3 5 - 3	31.3	4	0
5	02	22	11	00	4 - 3	33.4	4 - 3	32	02	22	20	00	4 - 3	29.3	9	0
6	02	27	09	10	4 - 3	31.3	4 - 3	30.5	02	27	20	00	*	*	10	50
7	03	01	10	00	3 - 3	31.4	3 - 3	31.4	03	01	19	50	*	*	9	50
8	03	04	09	30	4 - 3	29.7	4 - 3	29.6	03	04	10	00	4 - 3	29.5	0	30
9	03	11	14	00	1 - 1	32.1	1 - 1	32.1	03	12	19	00	4 - 3	27	29	0
10	03	26	08	00	1 - 1	33.7	1 - 1	30	03	.6	21	50	*	*	13	50
11	03	28	10	00	1 - 3	29.5	1 - 3	29.6	03	28	21	50	*	*	11	50

*No record

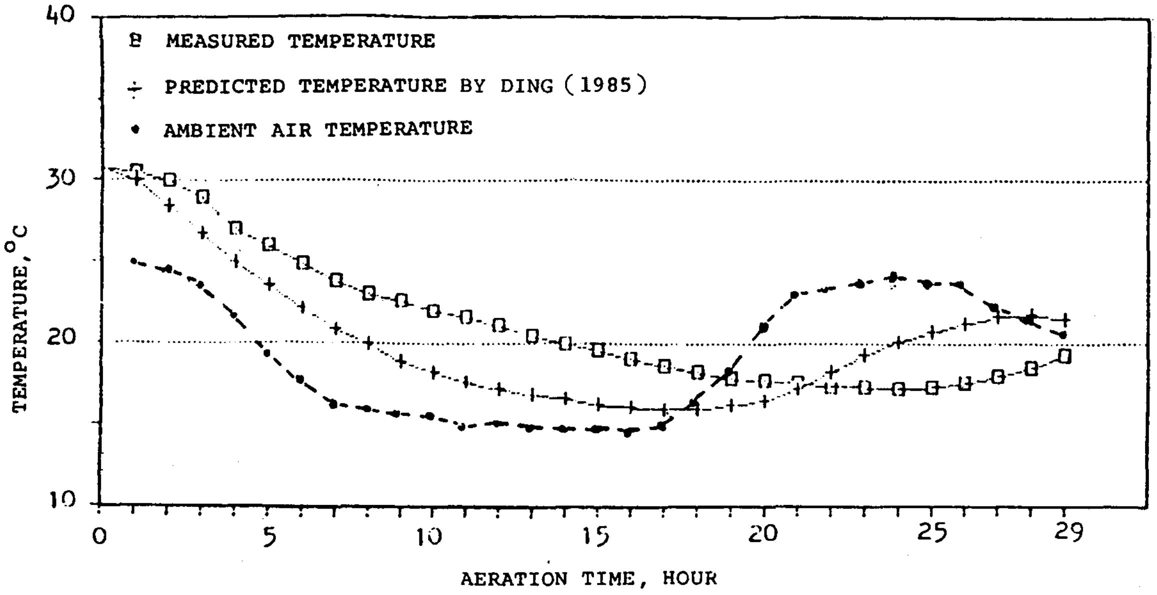


Figure 12. Predicted and measured temperatures 125cm from the steel bin bottom from 14:00 March 11 to 19:00 March 12, 1985.

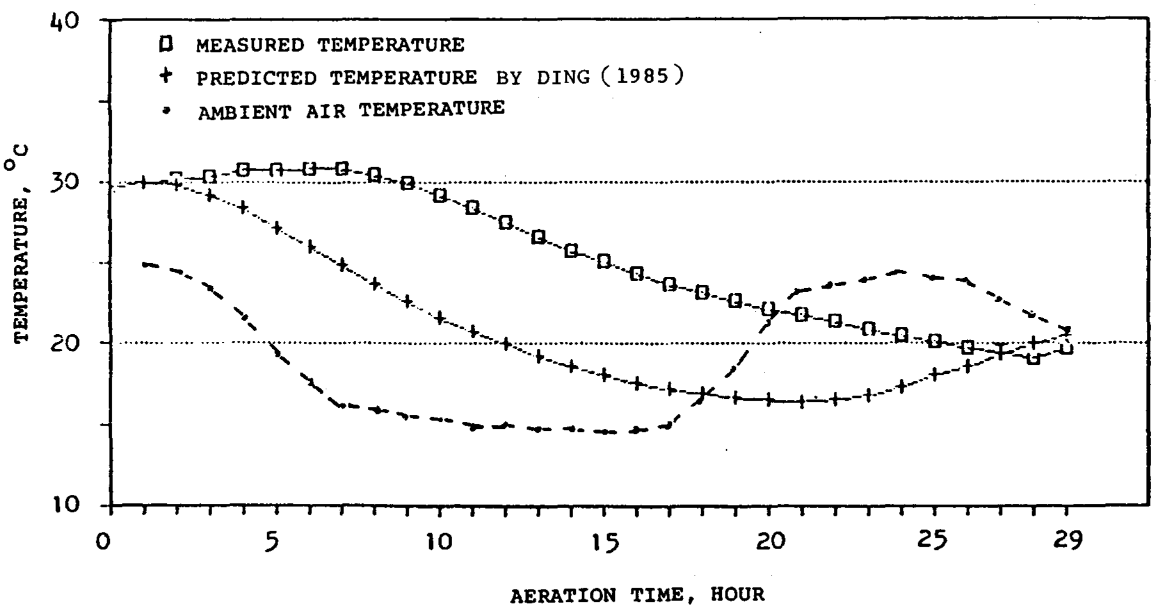


Figure 13. Predicted and measured temperatures 275cm from the steel bin bottom, from 14:00 March 11 to 19:00 March 12, 1985.

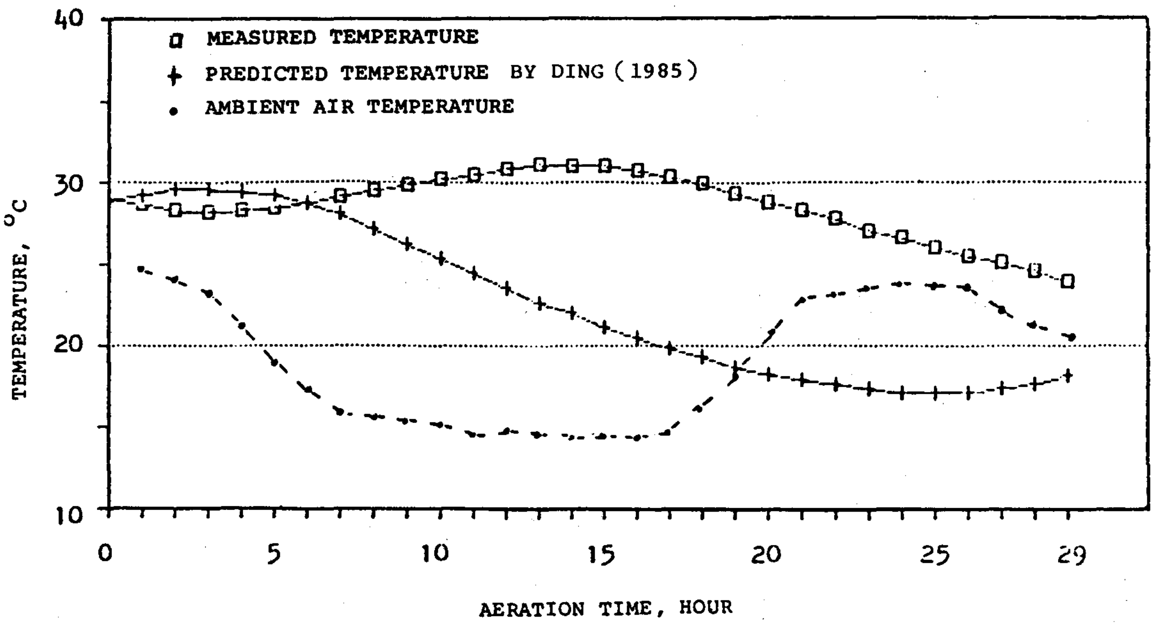


Figure 14. Predicted and measured temperatures 425cm from the steel bin bottom from 14:00 March 11 to 19:00 March 12, 1985.

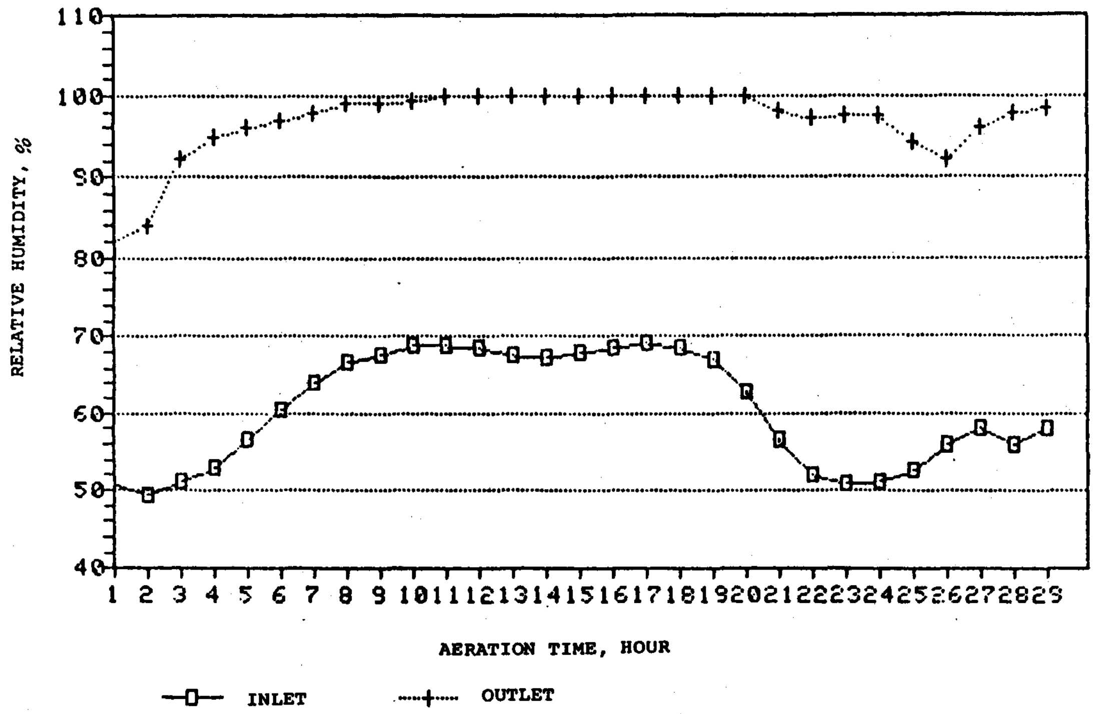


Figure 15. The relative humidity of inlet and outlet air during the aeration from 14:00 March 11 to 17:00 March 12, 1985.

Table 2. **Germination* of corn at three different layers in steel tank**

Layer \ Sampling date	8, January	23, January	7, February	25, February	11, March	27, March	3, April
Bottom	36.5 ± 3.2	35.5 ± 3.9	23.8 ± 11.8	20.5 ± 11.0	14.3 ± 8.61	15.5 ± 7.3	13.3 ± 9.3
Middle	38.8 ± 2.1	35.5 ± 2.7	24 ± 5.6	25 ± 4.6	14.3 ± 8.59	14.25 ± 8.2	9.8 ± 6.2
Top	39 ± 4.1	34.3 ± 6.5	26 ± 8.3	15.6 ± 7.6	12.6 ± 7.46	12.5 ± 7.4	9 ± 5.5

*Mean±Standard Deviation

Table 3. Germination* of corn at different cable locations and center (7) of steel tank

Cable No. \ Sampling date	8, January	23, January	7, February	25, February	11, March	27, March	3, April
1	36.7 ± 2.9	31 ± 2.9	25.7 ± 2.4	23.3 ± 3.4	21 ± 3.7	19.3 ± 0.5	14 ± 1.4
3	36.7 ± 3.7	41.3 ± 1.3	33 ± 3.3	27 ± 5.4	19.3 ± 0.9	17 ± 2.2	18 ± 6.2
6	38.7 ± 0.5	35.3 ± 2.1	27.3 ± 6.9	23 ± 2.3	13.77 ± 2.1	19 ± 1.6	10.77 ± 0.9
7	40.3 ± 3.9	32.7 ± 3.4	12.3 ± 5.4	8.2 ± 8.4	0.8 ± 0.9	1 ± 1.4	0 ± 0

*Mean±Standard Deviation

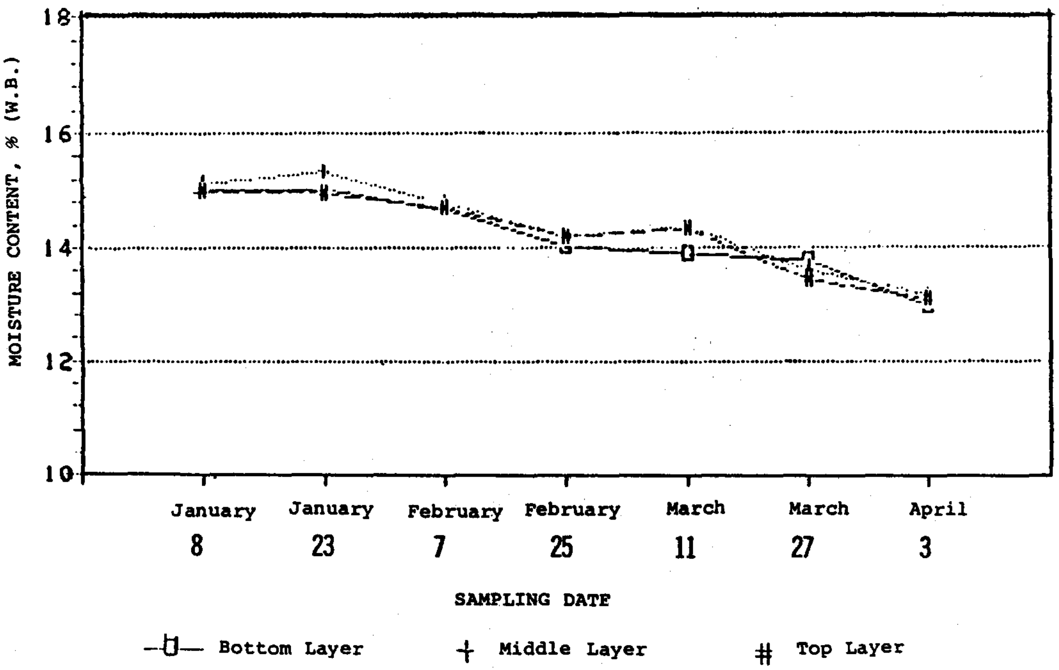
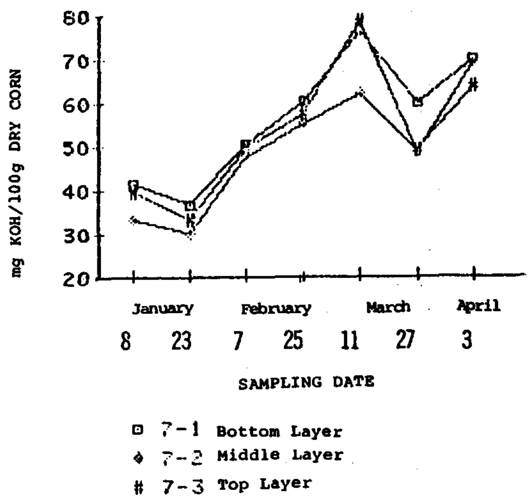
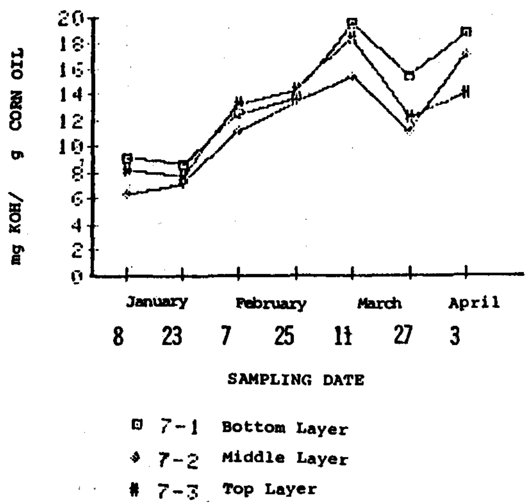


Figure 16. The change of corn moisture content varied with storage time at three different layers in steel tank



(a) on the basis of 100g dry corn sample



(b) on the basis of 1g corn oil

Figure 17. Fatty acid value varied with storage time near the center of steel tank at three different layers.

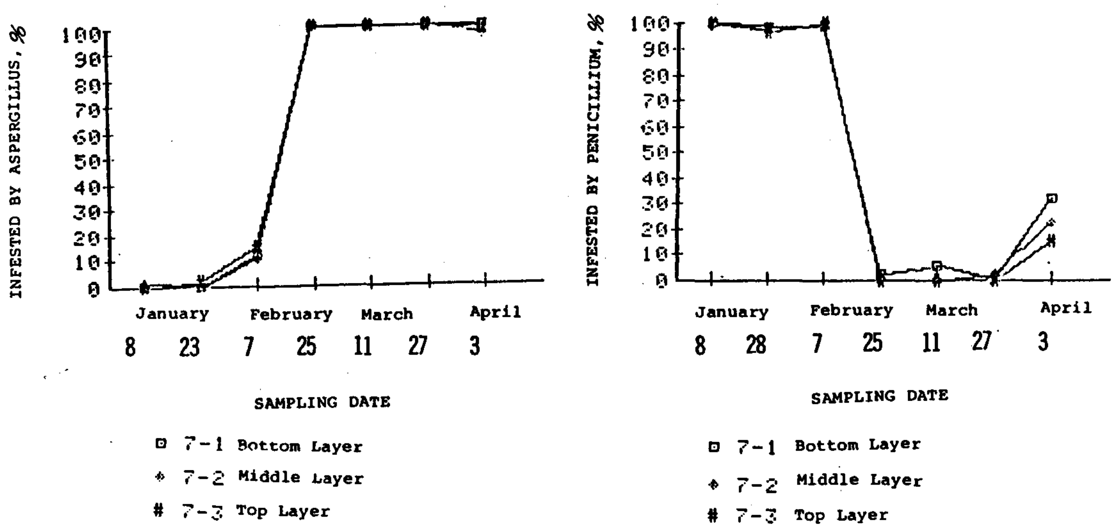


Figure 18. Corn infested by Aspergillus and Penicillium during the storage in the center of steel tank.

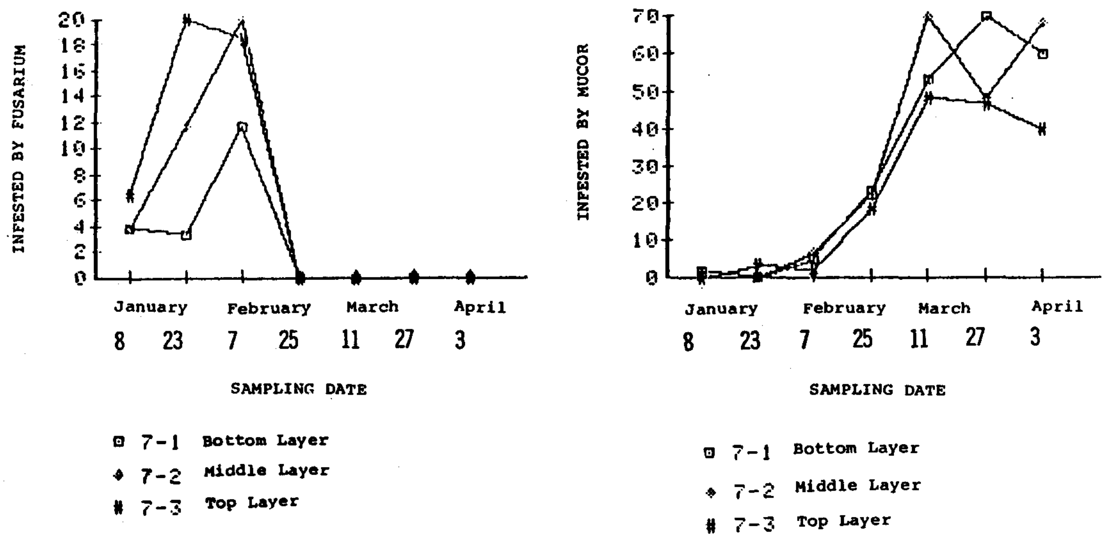


Figure 19. Corn infested by Fusarium and Mucor varied with storage time in the center of steel tank.

On December 20, 1985, Phostoxin (trade name of insecticide) was added during loading corn into the steel tank. This may be the reason we cannot find insects in the first 48-day storage. Then insect count increased significantly as shown in Figure 20. On April 3, the last samples were taken, kept in the room temperature for one month and then counted the amount of larva was 43, 48 and 71 per liter respectively at the top, middle, and bottom layers near the center of steel tank,

As shown in Figure 21, the highest measured temperature of corn in the concrete silo during the storage is 38°C after 63-day storage. Next day, started to aerate the corn. The total aerated time is 146 hours as listed in Table 4. This aeration effect could explain the corn temperature was up and down during the storage.

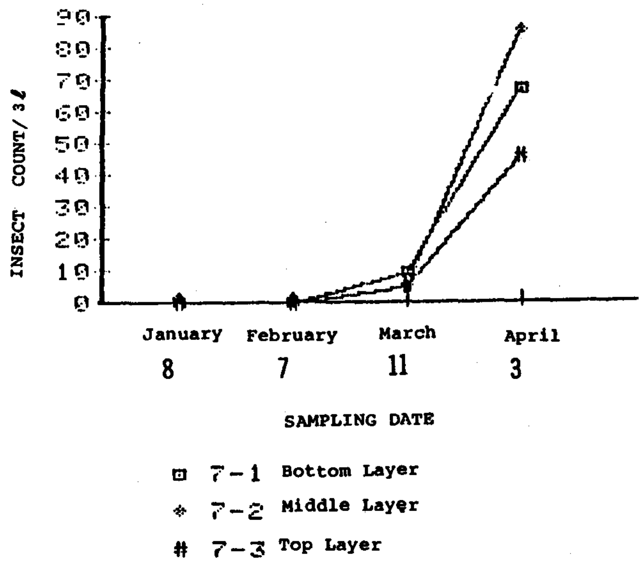


Figure 20. Insect count varied with storage time in the center of steel tank.

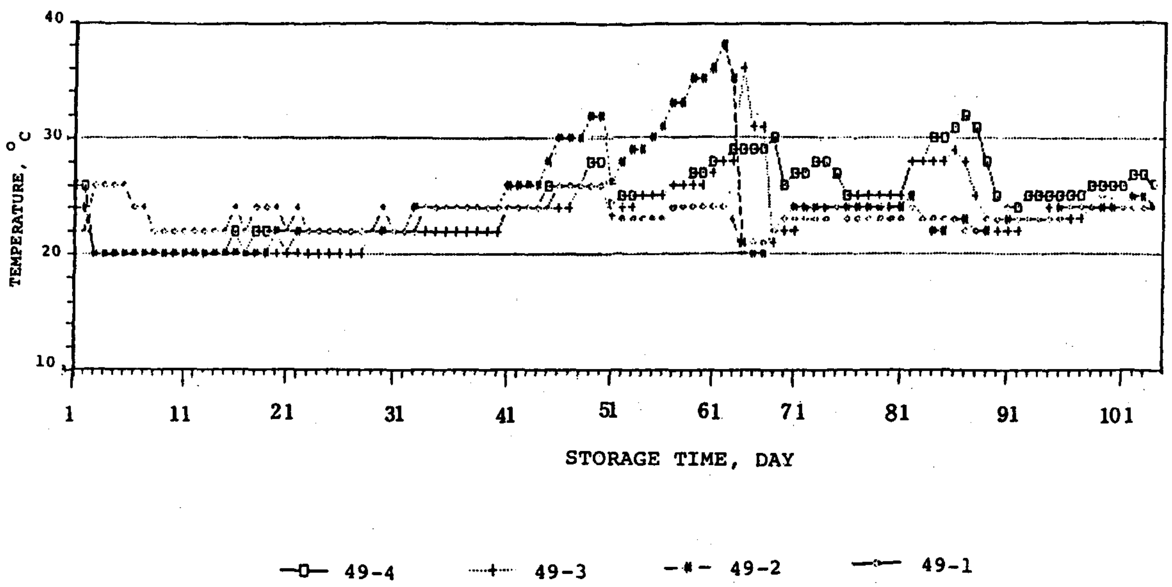


Figure 21. Measured corn temperatures of concrete silo daily at 15:00 from December 21, 1984 to March 31, 1985.

Table 4. Aeration schedule of concrete silo in 1985

No.	Starting Time				Stop Time				Aeration h.
	month	day	hour	min	month	day	hour	min	
1	2	22	11	00	2	22	22	00	11
2	2	23	08	00	2	23	22	00	14
3	2	24	15	00	2	24	22	00	7
4	2	25	08	00	2	25	22	00	14
5	2	26	08	00	2	26	22	00	14
6	2	27	08	00	2	27	22	00	14
7	3	11	14	00	3	11	22	00	8
8	3	12	14	00	3	12	22	00	8
9	3	16	08	00	3	16	22	00	14
10	3	17	08	00	3	17	22	00	14
11	3	18	08	00	3	18	22	00	14
12	3	19	08	00	3	19	22	00	14

The moisture content of corn in concrete silo varied with storage time at 4 different locations was shown in Figure 22. Due to applying 20hp aeration fan, maximum 2.4% of moisture content on the top was removed from the initial moisture content, 14.7%.

Table 5 showed the viability of corn in the center of concrete silo decreased with storage time, but kept better germination rate compared with Table 3 in the center of steel tank.

Figure 23 showed the fatty acid value changed with storage time and 4 different locations in the center of concrete silo. Basing on the 50mg KOH/100g dry corn as the highest allowable fatty acid value, the maximum storage time would be about 67 days that are 18 days longer than that stored in the steel tank.

Figure 24 showed a tendency of corn infested by Aspergillus at 4 different locations in the center of concrete silo. Figures 25, 26 and 27 also showed the same tendency in Penicillium, Fusarium, and Mucor acting in the center of concrete silo as in the center of steel tank.

Figure 28 showed insect count varied with storage time at 4 different locations in the center of concrete silo. In the initial 49 days, insects were under control by Phostoxin. The last sample taken on April 3 was kept in the room temperature for one month, and then counted the amount of larva was 79, 6, 56 and 175 per liter respectively at 49-1, 49-2, 49-3 and 49-4 locations.

Table 5. Germination* of corn near the center of concrete silo

Sampling date	January 7	January 23	February 7	February 25	March 11	March 27	April 3
Germination (%)	40.5±1.8	37.5±1.7	26.5±4.2	27±6.4	18.9±4.8	12.8±10.3	13.3±8.8

*Mean±Standard Deviation

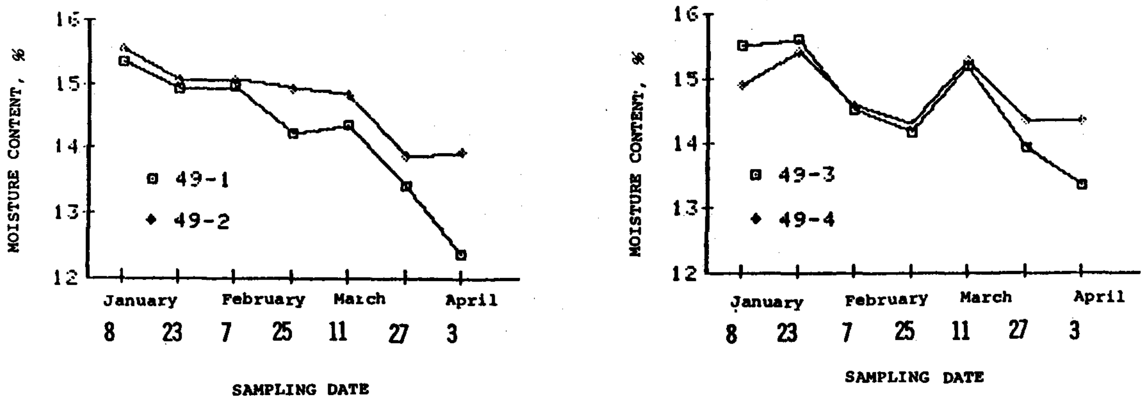


Figure 22. The moisture content of corn in concrete silo varied with storage time at 4 different locations.

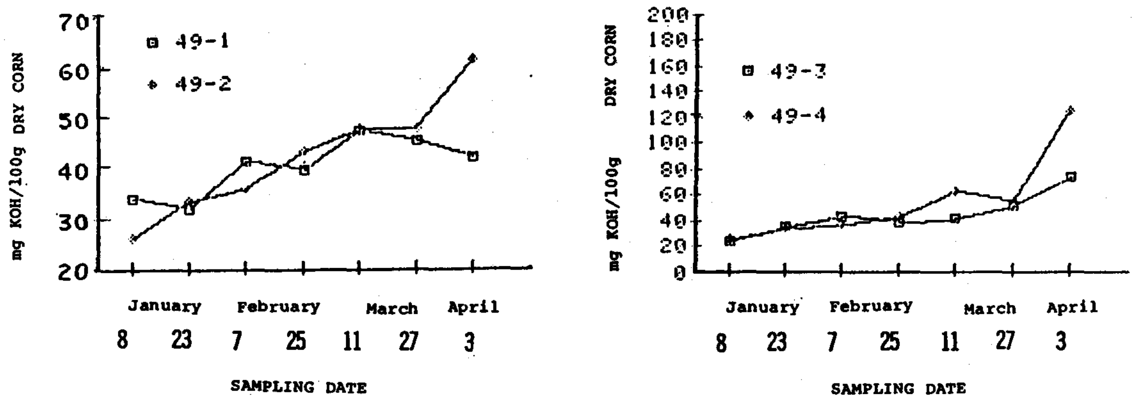


Figure 23. Fatty acid value varied with time at 4 different locations in the center of concrete silo.

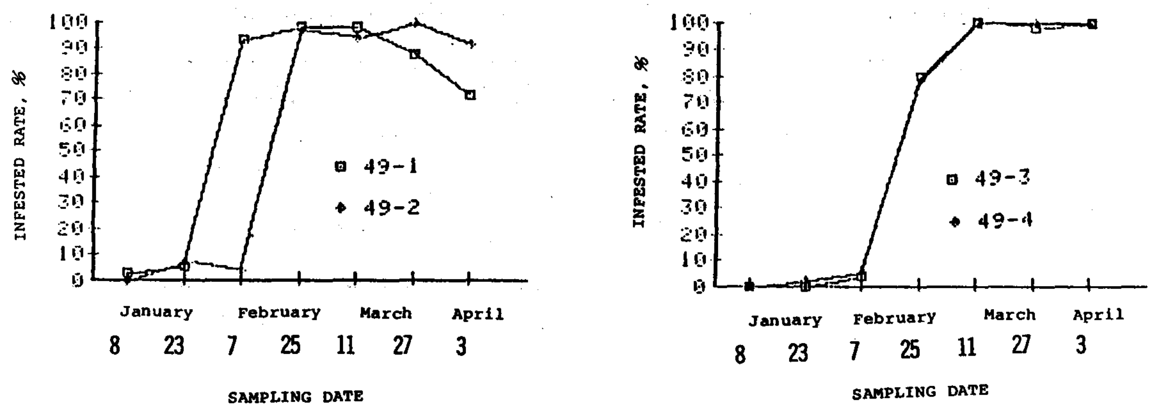


Figure 24. Corn infested by Aspergillus at 4 different locations in the center of concrete silo.

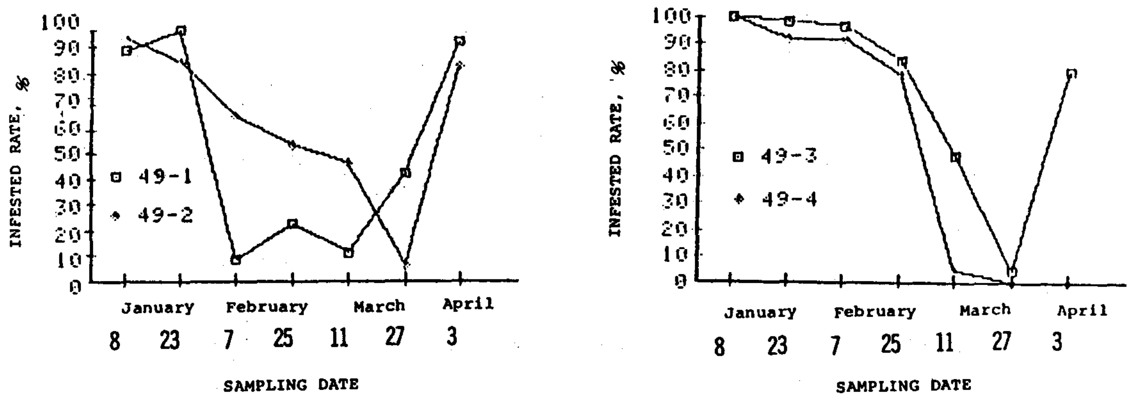


Figure 25. Corn infested by Penicillium at 4 different locations in the center of concrete silo.

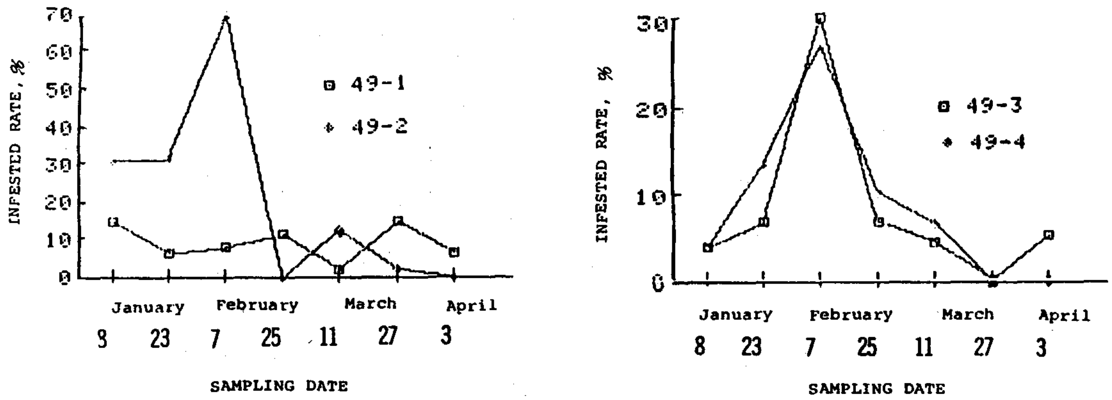


Figure 26. Corn infested by Fusarium at 4 different locations in the center of concrete silo.

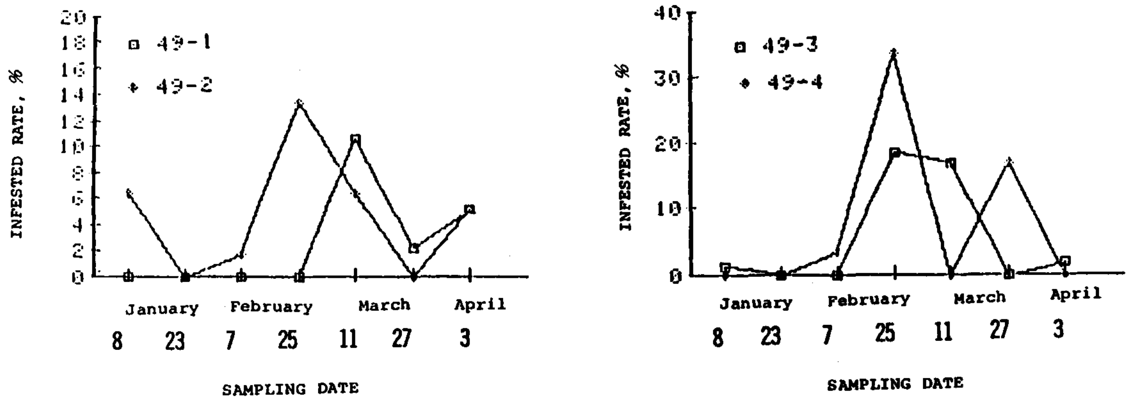


Figure 27. Corn infested by Mucor at different locations in the center of concrete silo.

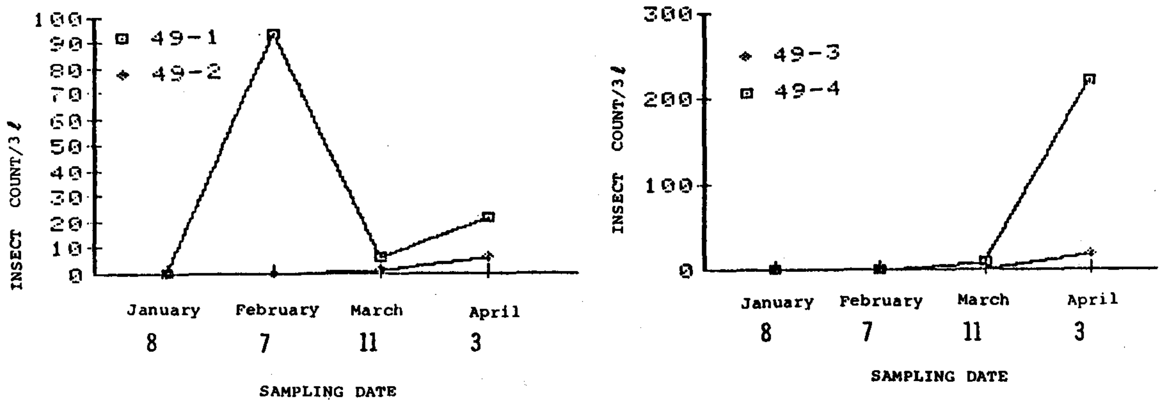


Figure 28. Insect count per 3 liters at 4 different locations in the center of concrete silo.

CONCLUSIONS

1. During the storage from December 20, 1984 to April 3, 1985, corn with 14.9% moisture content was loaded into an experimental steel bin, 5.32m diameter by 6.096m height. After 53-day storage, the maximum corn temperature near the center of tank was 41°C under the average ambient air temperatures between 12.5°C and 25.5°C and average relative humidity between 64% and 88%. During the same period, corn with 14.7% moisture content was stored in a nearby concrete silo, 10m diameter by 28m eave height. The highest corn temperature was 38°C after 63-day storage.
2. To predict the temperature rise due to hot spots in a tank of corn, finite difference

equations were developed and applied to validate the existing biological activities by comparing the predicted with the measured temperatures.

3. To cool down hot spots, corn stored in the steel and concrete bins was aerated. After 116.7-hour intermittent aeration in 3.5-month storage, the reduction of corn moisture content was 1.9%, 1.7% and 1.8% respectively at the bottom, middle and top layers of steel tank. After 146-hour intermittent aeration in 3.5-month storage, the reduction of corn moisture content was 1.4%, 0.8% and 2.4% respectively at the bottom, middle and top layers of concrete silo.
4. After 3.5-month storage, the germination of corn near the center of steel tank and concrete silo was 0% and 13% respectively.
5. Basing on 50mg KOH/100g dry corn as allowable fatty acid value, the allowable storage time was 49 days and 67 days respectively in the experimental steel and concrete silo during the winter and spring seasons in the southern Taiwan.
6. The amount of corn infested by Aspergillus increased from 47.5% to 98.3% after 3.5-month storage in the steel tank. Similarly, the infested rate of corn stored in the concrete silo was changed from 76.1% to 87.8%.
7. After 3.5-month storage, the amount of corn infested by Penicillium was from 67.5% to 22.8% and from 41.7% to 86.7% respectively in the steel and concrete silo.
8. By properly applying insecticide, Phostoxin, it may be very effective to control the development of insects in the beginning of 48-day storage.

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