APPLICATION OF DRYING AGENTS FOR SMALL SCALE ON-FARM DRYING AND STORAGE IN HUMID REGIONS OF DEVELOPING COUNTRIES

by

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INTRODUCTION

The grain losses associated with harvesting, handling, and storing of food grains in developing countries are very serious problems. It is estimated that more than 40 percent of all food grains harvested is lost before consumption in some parts of the world, especially in warm, humid areas (Ives, 1968; Hall, 1970). These losses are due primarily to the lack of adequate facilities and improper ways of handling, drying and storing food grains.

Although it is recognized that the solution of over-all grain marketing problems in developing countries is largely dependent upon how well the storage, handling, and drying problems at farm and local levels are treated, very little attention has been given to these problems. In developed countries such as the United States, Canada, and England, grain storage, handling, and drying problems have been well studied. But a certain developed technology cannot readily be adopted in developing countries, especially at farm and local levels, because of climatic and economic reasons. In addition, due to the lack of competent personnel and availability of utilities around farm and local levels for operating advanced grain storage, handling, and drying systems, it is sometimes impractical to introduce such systems at these levels.

The grain dried to a safe storage condition very often regains the moisture in humid areas, so the grain must be recycled through a dryer or other drying facility for further storage. Besides the added costs due to such a grain recycling process, some losses in grain quantity and quality are also expected at each recycling. At the present time, no effective and economical means of maintaining the grain quality during storage that can be applicable to farm and local levels at humid conditions are available.

Therefore, our effort will be devoted to developing a simple and inexpensive storage unit and method that would not require electricity and fuel. Also, the storage unit and method to be developed should be easily maintained and operated by unskilled persons. The approach proposed in this project is to place an adsorbent (drying agent) into a grain mass for the purpose of creating a drier air condition within a storage unit such that the grain quality can be maintained.

LITERATURE REVIEW

Relationship Between Cereal Grains and Water Vapor

When considering water-grain relationships, it should be noted that cereal grains are hygroscopic materials. In the relationships between water and grain, the dried grain takes the role of an adsorbent while the water is the adsorbate. Water adsorption on grains was discussed by Anderson (1954), Oxley (1948), Chung (1966) and Henderson (1970). The adsorption process may be classified as either physical (van der Waals) or chemical, depending on the nature of the forces involved. The physical adsorption is caused by the intermolecular forces between molecules of water vapor and the surface of the adsorbent. The formation of this physically adsorbed layer is generally considered to be similar to the condensation of a vapor. This physical adsorption is almost totally responsible for the adsorption in water-grain relationships. Fig. 1, a typical adsorption-desorption curve taken from Chung (1966), displays the Characteristic of equilibrium moisture content always being higher for desorption than for adsorption.

An important property of hygroscopic materials is the equilibrium moisture content as it has a direct relationship to storage and drying problems. The moisture content of a material changes as it gains and loses water. In a stable environment, after a time, the grain will reach a stable point depending on the temperature and relative humidity of the interstitial air. The relative humidity is determined by the vapor pressure produced by the hygroscopic moisture in the material, and the saturated vapor pressure of pure water at the same temperature. Because adsorption and desorption of water vapor on cereal grains is of a great importance in grain storage,

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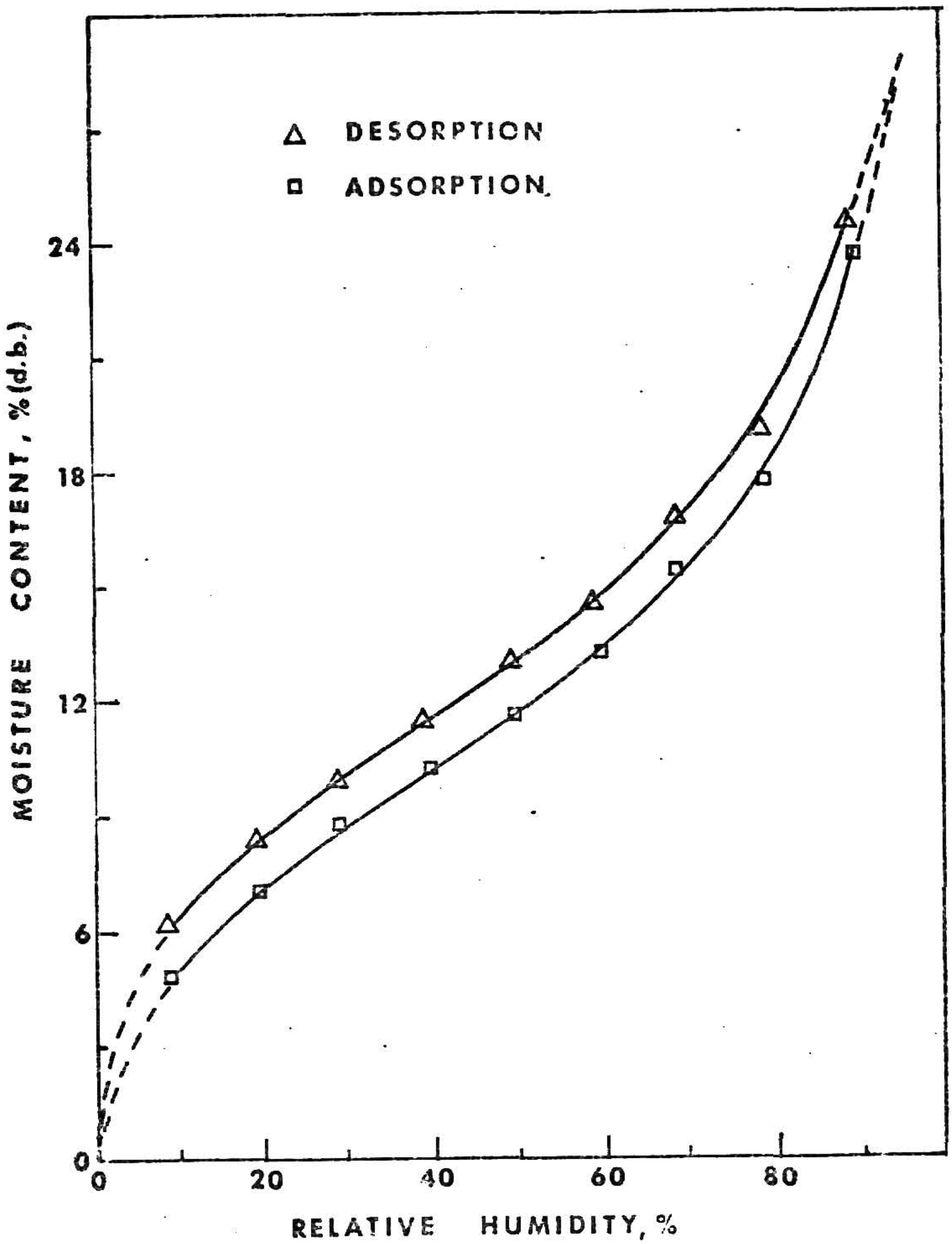

Figure 1. Adsorption-desorption isotherms of corn at 22 C showing hysteresis effect, Chung (1966).

handling, drying and other grain processing, many studies have been made to develop isotherm equations. Chung and Pfost (1967), Dunstan (1972), and Henderson (1950) discussed at length their research leading to the development of isotherm equations.

In water-grain relationships, the drying process must be considered. During the drying process, vapor pressure exerted by the relative humidity of the air surrounding the grain is lower than the vapor pressure exerted by the grain; therefore, moisture moves from the grain to the air. The drying machanism, as stated by Lebedev (1961), is the transfer of moisture within the kernel and the evaporation from the surface of the kernel with the drying rate depending on the intensity of moisture transfer from within to the surface. Therefore, as the moisture content of the kernel decreases, the intensity of moisture transfer also decreases and the drying rate drops off.

Relationships Between Other Adsorbents and Water Vapor

The Chemical Engineer's Handbook (1950) classifies drying agents into four types: (1) adsorbents such as silica gel that remove water vapor by surface adsorption and capillary condensation, (2) solid adsorbents which remove water vapor by chemical reaction, (3) deliquescent absorbents which remove water vapor by chemical reaction and (4) liquid absorbents which remove water vapor by absorption.

Solid desiccants retain water by one or more of the following mechanisms: (1) adsorption by chemical reactions as in hydrates and hydroxides, (2) adsorption in a monomolecular layer on the desiccant surface, and/or (3) adsorption by capillary condensation when the desiccant is highly porous. Fig. 2 shows the isotherms for a few solid adsorbents.

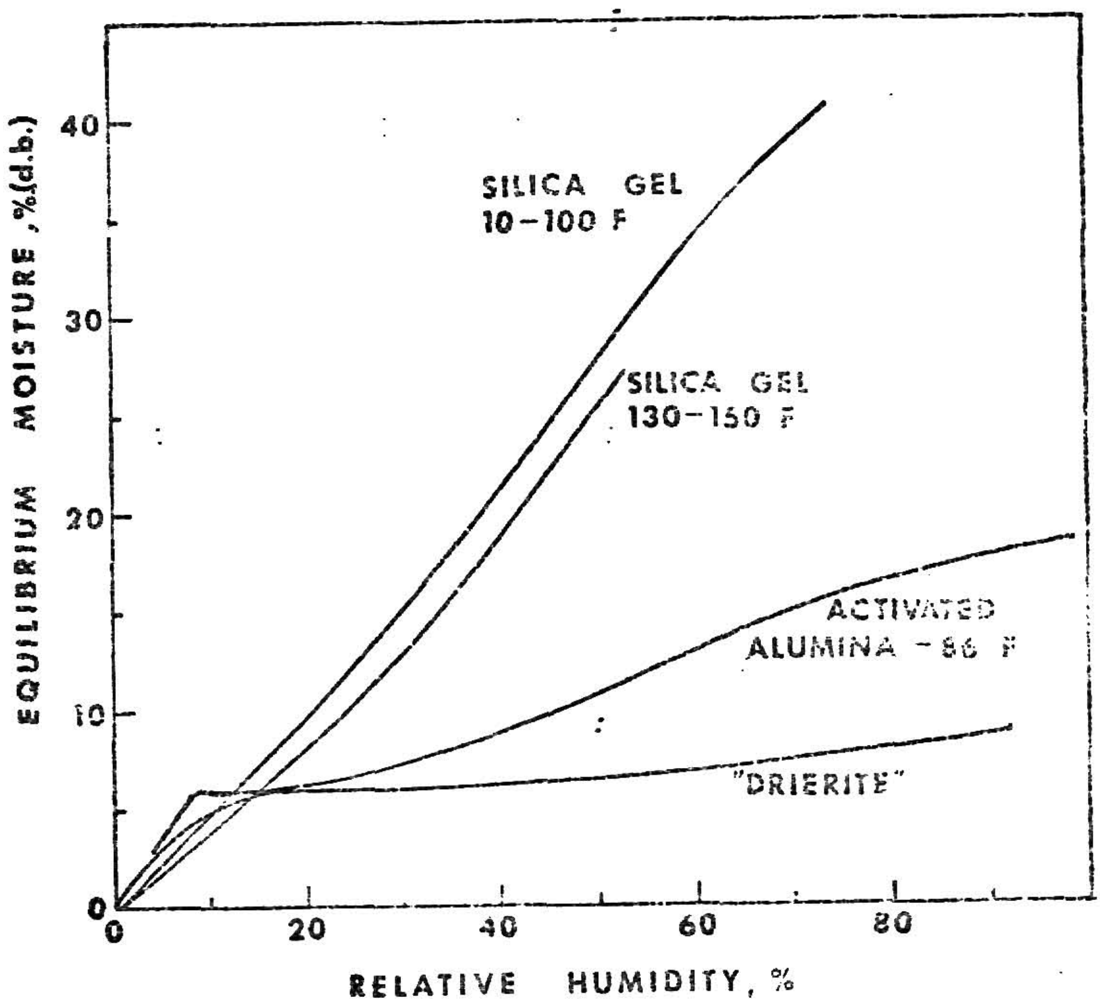

Figure 2. Equilibrium moisture for solid desiccants, Chemical Engineer's Handbook (1950).

When water vapor is adsorbed by a desiccant, heat is released. Since the adsorption process is exothermic, it is difficult to maintain isothermal conditions. Therefore, most adsorbent beds operate adiabatically. As heat is released, the temperature of the bed rises; and the rate of adsorption is decreased. Chi and Wasan (1970) gave the theoretical analysis for both an isothermal process and the adiabatic process. They concluded that for unsupported fixed adsorbent beds, the isothermal and adiabatic models sufficiently describe the system.

The discussion in the Chemical Engineer's Handbook is reinforced by the work of several researchers. Ahlberg (1939) in his paper dealing with adsorption of silica gel concluded that for a given humidity, the amount of water adsorbed per unit weight of gel at saturation is independent of temperature as long as the critical temperature (600 F) is not exceeded. If the rate of diffusion of the condensable vapor into the interior of the gel is a significant factor, the rates of adsorption at a given relative humidity should increase with temperature.

Patrick, Frazer, and Rush (1927) showed that the adsorbing power of silica gel under static conditions is affected by the purity of the gel and the temperatures to which it has been subjected. They found that a highly purified gel decreases in adsorbing power only slightly after being subjected to high temperatures while the presence of small quantities of sodium salts may greatly affect the adsorbing power after heat treatment.

Miller (1920) in his work with silica gel also supported the previous discussion. He found that vapors of liquids with high boiling points were more strongly adsorbed than vapors from liquids with low boiling points. In addition to showing that adsorption decreased with increasing temperature, he showed that the greater the partial pressure of a vapor, the greater the adsorption. Thus, the suggestion that the vapor was condensing on the adsorbent. He also showed experimentally that with increasing the relative humidity, the amount of vapor adsorbed also increases.

Grain Storage Problem

Cereal grains are relatively easy to preserve provided they are kept dry and free from insect and rodent infestation. Anderson (1954), Mackay (1967), Ives (1968), Oxley (1948), Matthes, Welch, Delouche, and Dougherty (1969) and Hall (1970) discussed various factors affecting grain quality and described the things that can and do happen to grain during storage.

Cereal grains are actually seeds in which life is being preserved in the dormant state. This dormancy is greatly affected by the water content and temperature of the seed. Also, insects, fungi, and bacteria are almost always present on or under the seed coat of harvested grain. Both the fungi and bacteria are dormant at low temperature and moisture; however, molds and bacteria grow at accelerating rates as the relative humidity increases.

During the storage of grains, translocation, and migration of moisture from one zone to another normally occurs. This is caused by temperature differences within the stored grain. The larger the temperature gradient, the greater the moisture transfer. The movement of air within the storage is the medium by which the moisture transfer takes place. In a given storage system, the air movement patterns are dependent upon the temperature differentials and the convective air flow process.

Warm air has a greater moisture carrying capacity than cool air for the same relative humidity. As the warm air cools, the humidity of that air increases. Therefore, the equilibrium (between the air and the grain) is unbalanced, and moisture must move from the air to the grain.

This accounts for the formation of pockets of high relative humidity along the cool, shaded side of the bin, and also in the upper layer and outer regions of the storage bulk. The last two areas are where the initial cooling takes place in the evening as the ambient air temperature drops. These small initial changes in relative humidity due to moisture migration often cause increased insect and mold activity.

The moisture translocation, described above, is usually a slow or maybe even negligible process unless the temperature gradient is very steep. Then, the phenomenon of moisture migration becomes an important factor in grain storage.

Anderson (1954) lists the factors influencing deteriorative changes as 1) moisture, 2) temperature, 3) oxygen supply, and 4) condition or soundness of kernels. The deterioration of grain may or may not be detectable by visual appearance or odor. However, the indices of deterioration as listed by Anderson (1954), 1) general appearance, temperature, odor, kernel damage, insects; 2) acidity; 3) disappearance of non-reducing sugars, can be measured by laboratory tests.

During the storage of cereal grains, molds and fungi are primarily responsible for respiration, heating, and chemical deterioration of damp grains; but, insects are the main contributor to grain damage in dry grains. Molds usually will kill the germ and cause high rates of water and heat production, in turn destroying the nutritive value of the grain.

Generally speaking, an easy check for deterioration is to see if there has been a loss in germinative power. However, a decrease in viability is not always a positive check for serious damage as loss of germination is usually caused early in mold development.

The keys to safe storage are moisture content and temperature of the grain. For a good storage system, a) the grain must be protected against increases in moisture content and temperature, and b) the grain must be protected from loss due to insects and rodents.

Types of Grain Storage and Conditioning

According to Ives (1968) grain preservation in humid areas requires three operations: (1) conditioning, (2) handling, and (3) storage. The process of conditioning includes cleaning, grading, deinfesting, and drying. Drying is of the first priority; the others follow. Successful storage depends on good management as well as good functional and structural design of storage structures. Good functional design provides for the inspecting, treating and moving of the product.

When considering conditioning for storage, one almost automatically thinks of drying. Several methods are available for drying in various regions of the world. These, as described by Hall (1970), include 1) field drying, 2) sun drying on a patio, 3) small household driers employing heat treatment or the use of a disiccant, 4) natural ventillation, 5) mechanically forced unheated air, and 6) mechanically forced heated air.

Field drying takes place before harvest and should be used if at all possible. However, in many places, this is not feasible because harvesting to reduce heavy field losses must be done before the grain is sufficiently dried. In many areas, the climatic conditions don't allow the grain to dry to a safe storage level.

Sun drying is another method that should be used if possible. However, it also depends on the weather conditions and requires a great deal of labor. Another natural method of drying is to put the commodity in a storage unit that permits free air ventillation such as the corn crib. In such a unit, it may take a month or more for the total bulk of grain to reach equilibrium with the ambient air.

When the natural methods are not adequate, several artificial methods are available. They include drier fans driven by internal combustion engines or electric motors and various types of plenum chambers. In the latter, heated air (forced or natural flow) passes through the chamber and up through the chamber and up through wet grains placed in bulk storage units, shallow trays or sacks. Another method involves the use of a raised granary beneath which fires are lit. The heated air rises through the grain, but leaves the grain with an unwanted odor. Still another method outlined by Creighton and Dexter (1948) used wood blocks that had been soaked in a desiccant, dried, and then placed in an air-tight can along with the grain. Many other types and special application driers are available, but the ones listed are typical of those being used today.

Typical storage facilities for tropical areas are mentioned by several authors: Hall (1970), Ives (1968), McFarlane (1970), Pingale (1965), Herum and Tripleform (1969). Many of the common methods are for very small amounts of grain. These include baskets woven from grass, gourds coated with oil, clay pots, and storage bins made from mud. A number of larger units are made from plant fibers, some coated with mud, and many are raised off the ground to decrease rodent damage. Many areas make use of underground pits while others use pole frame vertical racks.

In some areas research has been done using a plastic material between two mud layers. Results have been encouraging, but the storage facility is not rat-proof.

More modern facilities for sack or bulk storage use concrete, wood, and metal as construction material.

In reviewing grain conditioning and storage problems of developing countries, especially humid regions, it appears that there are no grain conditioning and storage methods and practices which are adequate enough to be used widely in the preservation of grain without loss and damage for humid areas. Perhaps, a few indigenous types of storage units may be adequate to be used for a small grain storage at farms but performance data with respect to grain quality and quantity losses are not yet available to assess their potential uses.

Furthermore, a certain developed technology cannot readily be adopted in developing countries, especially at the farm level, because of climatic and economic factors. Therefore, much work is needed to develop a simple and inexpensive storage unit and method that will be readily applicable for on-farm storage in the humid regions of developing countries.

OBJECTIVES

The broad objective of this investigation is to develop a simple and inexpensive grain storage unit or method which can effectively be used at farm and local levels in humid areas of developing countries in order to preserve the quality of grain.

The specific objectives are as follows:

1) To find an adsorbent or adsorbents which can be used for grain storage and drying in tropical areas of high temperatures and high relative humidities.

2) To determine the grain to adsorbent ratio needed at different initial moisture contents for a safe storage.

3) To determine an effective internal distribution for the adsorbent at different moisture contents.

4) To analyze drying agent performance with respect to grain quality in relation to mold growth and rate of moisture transfer.

5) To study the economic feasibility of the proposed grain storage and drying practice.

MATERIALS AND METHODS

Grain used for the initial series of tests was shelled yellow corn at about 12% moisture content (wet basis), which was purchased at a local elevator in spring of 1972. Unfortunately, no information on the history of the corn purchased (crop year; condition of grain at the time of harvesting, after harvesting and just before drying; how it was dried; etc.) could be obtained. Absorbents (desiccants or drying agents) tested were lime, silica gel (6–16 mesh), "drierite" ($CaSO_4$), calcium chloride ($CaCl_2$) and salt (NaCl). Small metal cans, 7½ inches in diameter and 7½ inches deep, which hold about 10 lbs. of corn, were used as storage containers. Figure 3 shows these cans along with the other elements comprising the storage unit.

For positioning and placing the desiccant in a storage container, a small screen cylinder, approximately 5/8 inch in diameter was placed at the center of a container. Figure 3 indicates that the position of the cylinder is maintained by wiring it to a frame. Some containers had two, three, or four cylinders which were uniformly positioned in the containers (Fig. 4).

In the preparation of a sample for storage tests, several things had to be accomplished. First, the corn at 12% moisture content had to be wetted to the desired initial moisture content for storage tests. Usually the wetted corn was left in cold storage (50 F) overnight, or until the corn reached a desired moisture content. The initial moisture contents of corn selected for storage tests were 12%, 15% and 20% (w.b.). Next, the cans and cylinders were disinfected with Clorox solution.

Before corn samples at a given initial moisture content could be put into the cans, each can was marked with a sample identification code, the correct internal cylinder structure was constructed and placed inside the

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Figure 3. Elements comprising the storage container.

Figure 4. Internal view showing placement of cylinders and sacks.

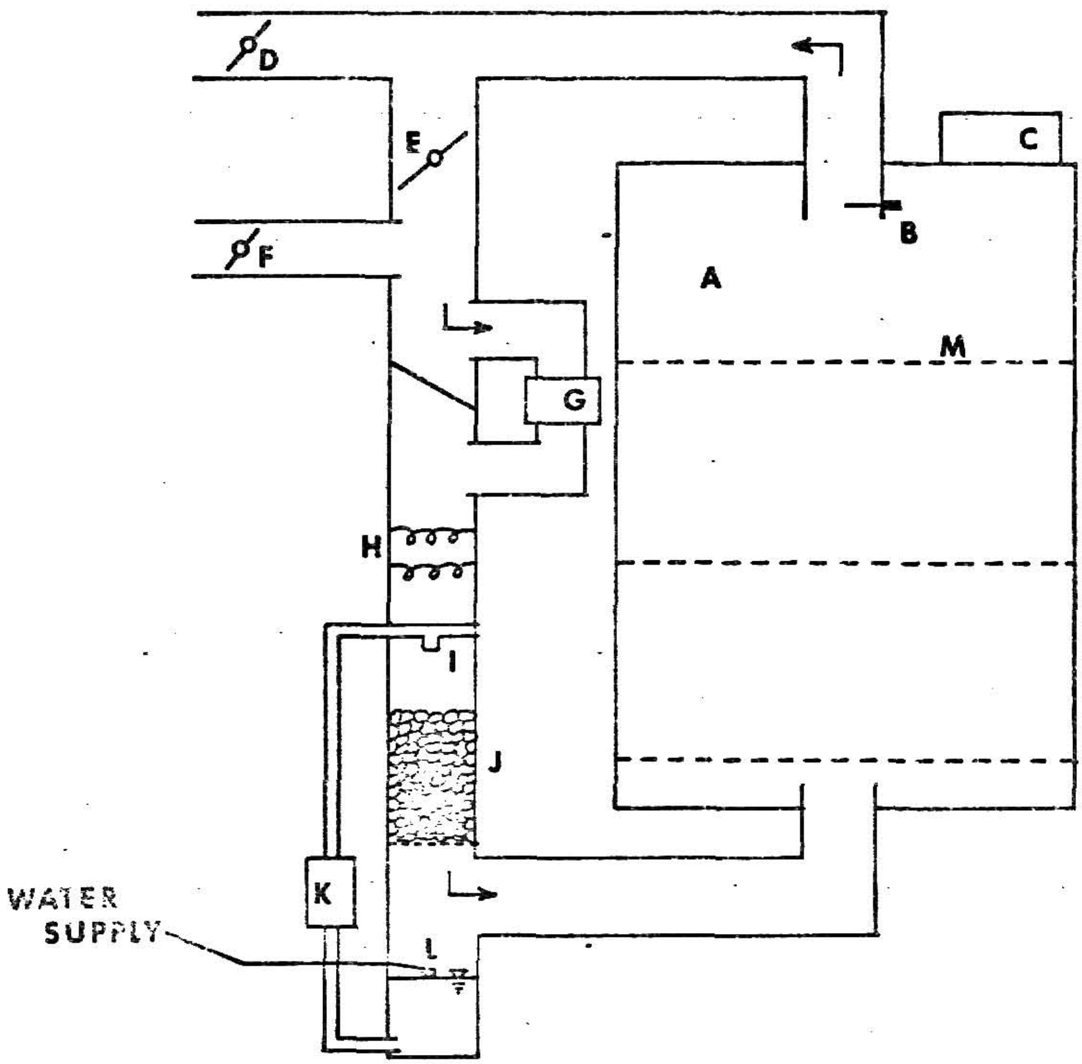
can, and a hole had to be punched in the lid for insertion of the thermometer. After these steps had been accomplished, the empty can with accessories was weighed and the weight recorded.

The cylindrical nylon cloth sacks of Figure 3 were filled with an adsorbent and weighed. During the can-filling process several moisture content recordings of the corn were made to get an average initial moisture content. The can was then weighed full before the sacks were put into place. With the completion of the weighing, the sacks were then placed in the can and the temperature of corn sample was recorded before placing the can in the climatic chamber.

The containers with corn and adsorbent were then placed in the climatic control chamber which was set to a desired environmental condition for storage test. Figure 5 shows a schematic diagram of the climate control apparatus used for simulating various environmental conditions. Figures 6 and 7, respectively, show the external and internal views of the apparatus.

The controlled chamber, A, in Figure 5 was made from an old refrigerator. The outlet valve, D, controlled the flow of air to the atmosphere, while the inlet valve, F, controlled the flow of air into the system from a refrigerated chamber. This control was mainly for controlling temperature below atmospheric conditions. For this experiment, both D and F were closed while E was completely open to permit free air flow through the system. The air fan, G, forced the air through the system. The air was heated by the use of a 1000-watt resistance heater controlled by the R7187D1019 Honeywell Controller, C, and the L703SA Honeywell Thermistor, B. This maintained the air temperature at a desired level.

After passing the heater, the air was forced through a rock column being sprayed with an antifreeze-water solution. This was the method used



A. Controlled Chamber

B. L7038A Honeywell Thermistor

C. R7187D1019 Honeywell Controller

D. Outlet Control Valve

E. Return Control Valve

F. Inlet Control Valve

G. Air Fan

H. 1000 Watt Resistance Heater

I. Sprinkler Nozzle

J. Rock Column

K. Water Pump

L. Float to Control Water Level

M. Shelves for Cans

Figure 5. Schematic diagram of climatic control apparatus.

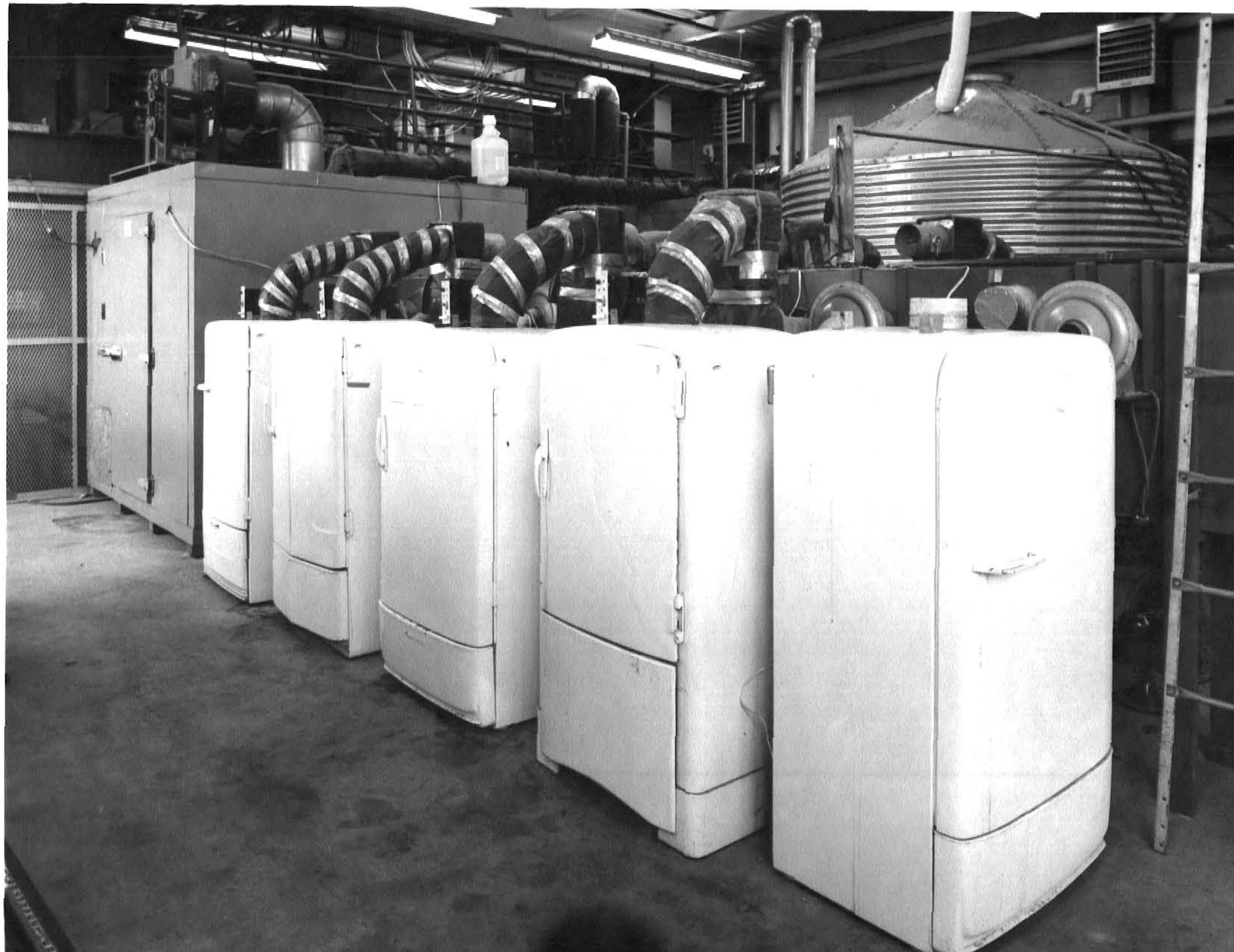


Figure 6. Climate control chamber apparatus.

Figure 7. Internal view of climate control chamber.

to control the relative humidity. The more antifreeze added, the lower the relative humidity. Once the ratio of antifreeze and water for a desired relative humidity was set, it was kept constant by the float mechanism in the bottom of the duct. After passing through the rocks, the moist air was circulated up through the controlled chamber and then back through the cycle. The Honeywell units continuously controlled the air temperature.

Environmental conditions set up for storage tests were 80-90% R.H. (relative humidity) at 90-95 F. air temperature and 90-100% R.H. at 90-95 F. Figure 7 shows the conditions of storage containers tested in an environment chamber: a) lid tightly closed (no air in and out), b) the lid loosely placed (considerable air in), and c) the lid tightly closed but a few small holes in the side of container (some air in).

The data which were recorded for each sample included the weight of the storage unit (corn included) with the adsorbent sack removed, the weight of the adsorbent, the temperature of corn, and the mold growth. The data were recorded twice daily for each sample (12 hour intervals).

When the desiccant was almost to the point of saturation, it was dried for approximately an hour at 95-100 C. by a laboratory oven. After drying, the desiccant was cooled and then placed back in the storage container. During the time of desiccant drying, the container was placed in the climate control chamber.

The procedure for the last series of tests differed somewhat from that indicated previously. The corn for these samples was newly harvested corn at 24% moisture (1972). The corn was cleaned by a Clipper, M-2B and then the corn was kept in cold storage (35-40 F) until ready for tests.

The corn was then dried to the desired initial moisture contents by a laboratory oven at 140 F. air temperature. All laboratory materials used (thermometers, bottles, etc.) were disinfected in alcohol before each use. Instead of taking several samples to the laboratory for weight and temperature determination, only one can was taken at a time from a climate control chamber. These changes reduced the time the cans were in the laboratory at room temperature for weighing and temperature determination from 20 to 30 minutes (the initial series of tests) to less than 5 minutes. Another change consisted of putting a plastic sheet over the top of closed containers in order to prevent the moisture condensate in a chamber from entering the sample containers.

For this series, the initial moisture contents of corn tested were 12, 15 and 20% (w.b.). The environmental condition was 90-95 F air temperature and 90-100% relative humidity while the containers were only open or closed. None of the storage containers had holes punched in the sides. Only silica gel (6-16 mesh) was used as an adsorbent in this series. The numbers of cylinders for placing silica gel bags (the ratio of grain to adsorbent) were 1, 2, 3, and 4, depending on the initial moisture contents of corn tested. Also some tests were conducted by placing small silica gel bags on the top layer of corn.

Silica gel was dried or regenerated by a laboratory oven at 130 C for 45 minutes after about 70% of its adsorptive capacity was used up, instead of waiting until a saturation point was reached. The frequency of regeneration also depended on the initial moisture content of corn. This will be discussed in a later section. In addition to twice a day determination of grain temperature, moisture changes in grain and moisture changes in silica gel, small samples were taken at 1, 3, 5, 10, and 14 days of storage for moisture content tests, mold count determination, and germination tests.

In Table 1, the experimental factors examined and the description of sample identification code used are tabulated.

Table 1. Experimental factors examined and description of sample identification code.

Grain:	a) Dry corn purchased at local elevator (12% w.b. rewetted) b) Newly harvested corn of 1972 (24% w.b.)
Initial Moisture Contents:	20%, 15%, 12%
Environmental Conditions:	a) 85 F, 80-90% R.H. b) 85 F, 90-100% R.H. c) 95 F, 80-90% R.H. d) 95 F, 90-100% R.H.
Type of Adsorbents:	Lime, $CaSO_4$, (drierite), $CaCl_2$, NaCl, Silica gel (6-16 mesh)
Number of Cylinders: (Grain to Adsorbent Ratio)	Zero to four cylinders w/wo sacks.
Condition of Containers:	Open, closed, holes in the side.

Sample Identification Code*:

12-0-0	12% initial moisture content, no cylinders, open can.
12-0-C	12% initial moisture content, no cylinders, closed can.
12-0S-0	12% initial moisture content, no cylinders with three sacks on top of grain, open can.
15-1-CH	15% initial moisture content, one cylinder, closed can with holes in the side.
20-3S-0	20% initial moisture content, three cylinders with three sacks on top of grain, open can.

*First two digit number indicates initial moisture content: 12, 15, or 20%.

The middle number-letter combination indicates number of cylinders (0-4) and the S indicates sacks on top of the grain.

The last symbols, O, C, and/or H indicate the condition of the can (i.e. open, closed, and/or holes in side).

RESULTS AND DISCUSSION

When the project was first set up, it was hoped that drying and storage of corn could be accomplished by drying agents. However, if this was not the case, the research was also intended to give a method of storing initially dry corn in the humid conditions. Storage of dry corn is not easy in tropical areas because the grain gradually acquires moisture from the air and either must be re-dried, or else it spoils in a short length of time.

A large number of tests had to be run during the preliminary stages because the correct ratios of grain to adsorbent had to be discovered for each initial moisture content. All facets of this study initially were trial and error as there was no literature to refer to for workable ratio, internal structure, or adsorbent. The various types of internal cylinder combinations with or without sacks can be viewed in Figure 4. In each individual sample, the rate of moisture transfer, the length of time until mold growth was visible, and the rate of mold growth were important factors. An analysis of these parameters dictated the next ratio for each initial moisture content.

In the preliminary series of tests, samples were stored in both 80-90 and 90-100% relative humidity chambers at 95 F. This practice continued until it appeared that preservation of good quality corn would be possible in the 90-100% R.H. chamber at 95 F. The possibility of having to reduce the severity of the climatic conditions was very real at the outset of the research. No preconceived thought of instant success was present. However, the research commenced at the most severe condition for if the system functioned at that level, it would succeed at any climatic condition less severe.

During the preliminary stages, corn samples at 12, 15, and 20% initial moisture contents were examined with various adsorbents (lime, $CaCl_2$, $CaSO_4$, NaCl and silica gel) at several ratios of the grain to adsorbent. The results indicated that lime just did not have the adsorptive capacity needed. It was found that $CaCl_2$ gave off tremendous amounts of heat when water vapor was adsorbed by it. Another problem was encountered with NaCl. NaCl gained moisture at a steady rate, but after a quantity of water had been accumulated, NaCl became a solution. $CaSO_4$ also had a steady rate of moisture adsorption, but the rate was too slow to prevent corn spoilage.

Besides the lack of adsorptive capacity of desiccants tested, their failures might have resulted from the following factors: 1) poor condition of the original corn used (corn purchased from a local elevator which contained considerable fines and foreign materials, and the later assay showed that the original corn had been considerably infested by mold even before storage tests); 2) some experimental procedures used (the grain was not cleaned before the tests, a storage temperature of wetted samples before the actual tests was not low enough, the thermometer used for checking grain temperature was not disinfected between samples, as the cans were weighed and temperatures recorded, they were subjected to a room temperature too long, creating moisture condensation problem, and some condensates seeped in through the hole provided for the thermometer insertion); and 3) regeneration of desiccant was done when the desiccant reached near saturation.

The preliminary tests showed that of the various drying agents tested, silica gel was the only one that had enough adsorptive capacity to be effectively used for drying and storing corn in humid areas.

Some experimental data on moisture changes in corn and silica gel, grain temperature change and grain quality changes in corn samples initially at 12, 15 and 20% moisture contents with various ratios of the grain to silica gel are tabulated in Tables 2 through 11 in the Appendix.

It was interesting to note differences in rate of saturation of silica gel. For a 20% initial moisture content sample, with open lid, as much as 90% of the adsorptive capacity of the gel was reached in the first half day after regeneration. For 15% sample with the lid open, only 70-80% of the adsorptive capacity was acquired while for a closed 15% sample, 65-75% of the capacity was reached in the first half day. At the 12% initial moisture content level, the silica gel in an open sample gained 60-70% of its water capacity while the closed sample was in the 50-60% range in the first half day. Saturation of the desiccant occured after 1½ to 2 days in the 15 and 20% samples while for the 12% samples 2½ to 3 days was required for saturation.

In Tables 2 and 3 the change in moisture content shows that one cylinder is adequate for a closed sample, but that for the open can one cylinder will not keep the corn dry. Tables 4 through 6 show data for 15% samples at 1, 2, and 3 cylinder ratios. The effects of changing the ratio on the rate of drying are shown in Figure 8. It shows that as the ratio increases, the drying rate increases. The increase from one to three cylinders is a decrease in grain to adsorbent ratio from 160:1 at one cylinder to 52.5:1 at three cylinders. These curves indicate that at 15% initial moisture content in open cans, one cylinder causes very little drying while two or three cylinders show a marked increase—the two cylinder sample drying 2% in 14 days and the 3 cylinder can drying 3.3% in the same two-week period. However, in Tables 5 and 6 mold growth is indicated after 9 days in the two cylinder sample although the three cylinder sample shows no visible mold growth after three weeks in storage.

The data from the samples indicating change of ratio in the 20% samples is presented in Table 7 and 9. Here again, the difference in rate of drying

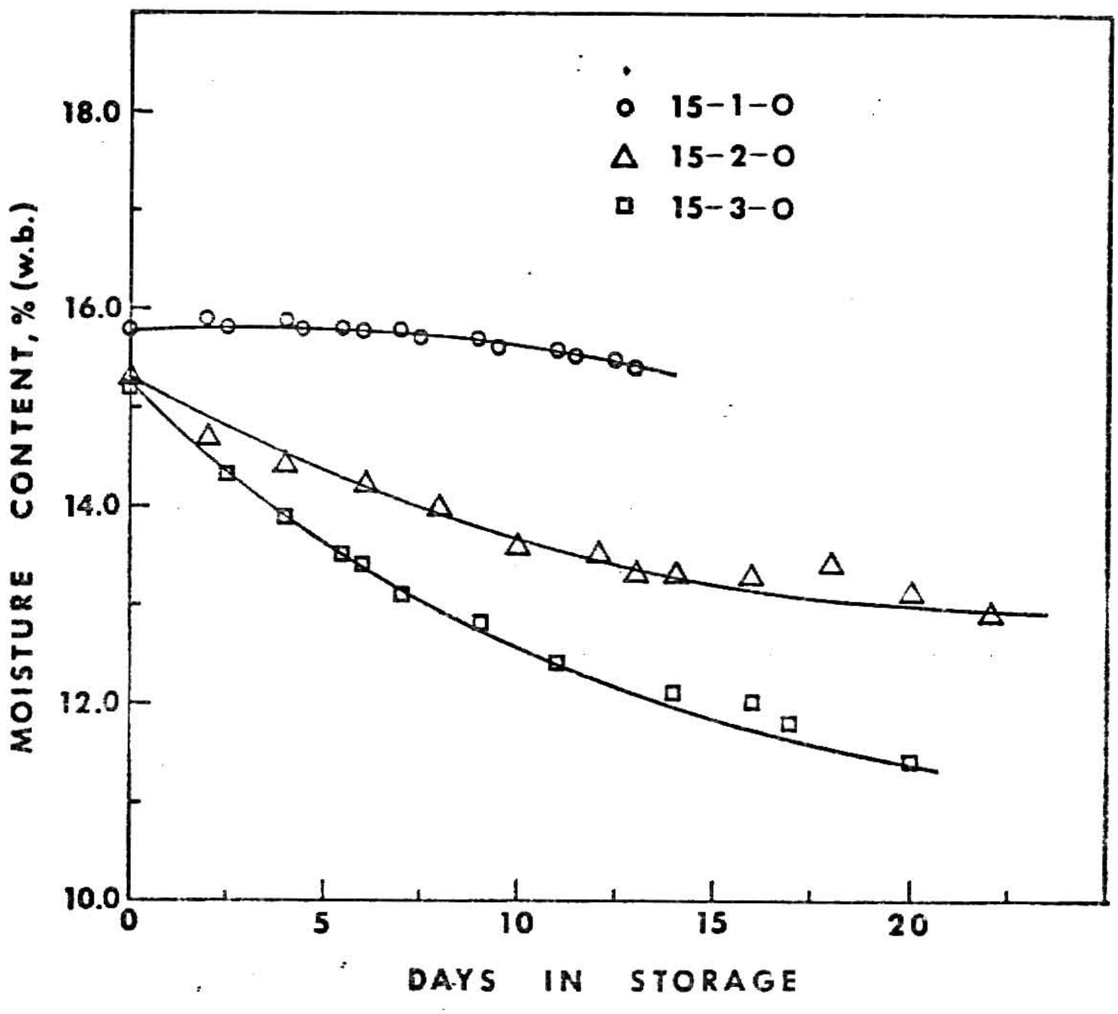


Figure 8. Moisture content versus days in storage for corn samples at 15 percent initial moisture content with silica gel in one, two, and three cylinders in an open container under 95 F and 90-100 percent R.H.

and rate of mold increase is as predicted for the 1 and 3 cylinder samples, but for the 4 cylinder sample of Table 9, rate of drying is slower and mold developed at a faster rate. However, the sample of Table 9 was kept in the cold storage chamber long enough for the mold growth to begin even before the sample was placed in the storage chamber. The rate of drying was probably affected by the mold already present in the system.

Figure 9 indicates what happens to corn that is subjected to a climatic condition of 95 F and 90-100% relative humidity. The upper curve, a sample initially at 12% moisture content (the upper curve), gained one percent moisture in eleven days. This sample was a can with no adsorbent present and with the lid on loosely (Figure 7, the cans on the left). A corn sample similar to that on the right in Figure 7 with the lid closed and holes in the side (the lower curve) only gained one quarter of one percent in the same eleven days. By referring to Tables 10 and 11, one can see that the open sample showed signs of mold growth after 8 days in storage while the closed sample showed no visible signs of mold growth after 25 days.

Some failures were observed in a few storage tests. Again these failures might have resulted from some of the reasons given in page 26. In general, the tests with silica gel showed a definite feasibility of storing corn without deterioration even at extremely adverse storage conditions. Therefore, the final series of tests were planned under revised experimental techniques and procedures based on the preliminary tests.

The grain used for these tests was newly harvested yellow corn that had been cleaned before the tests.

The other deviation from the previous tests was that three small silica gel sacks (the grain to silica gel ratio, about 140:1) were placed on the top

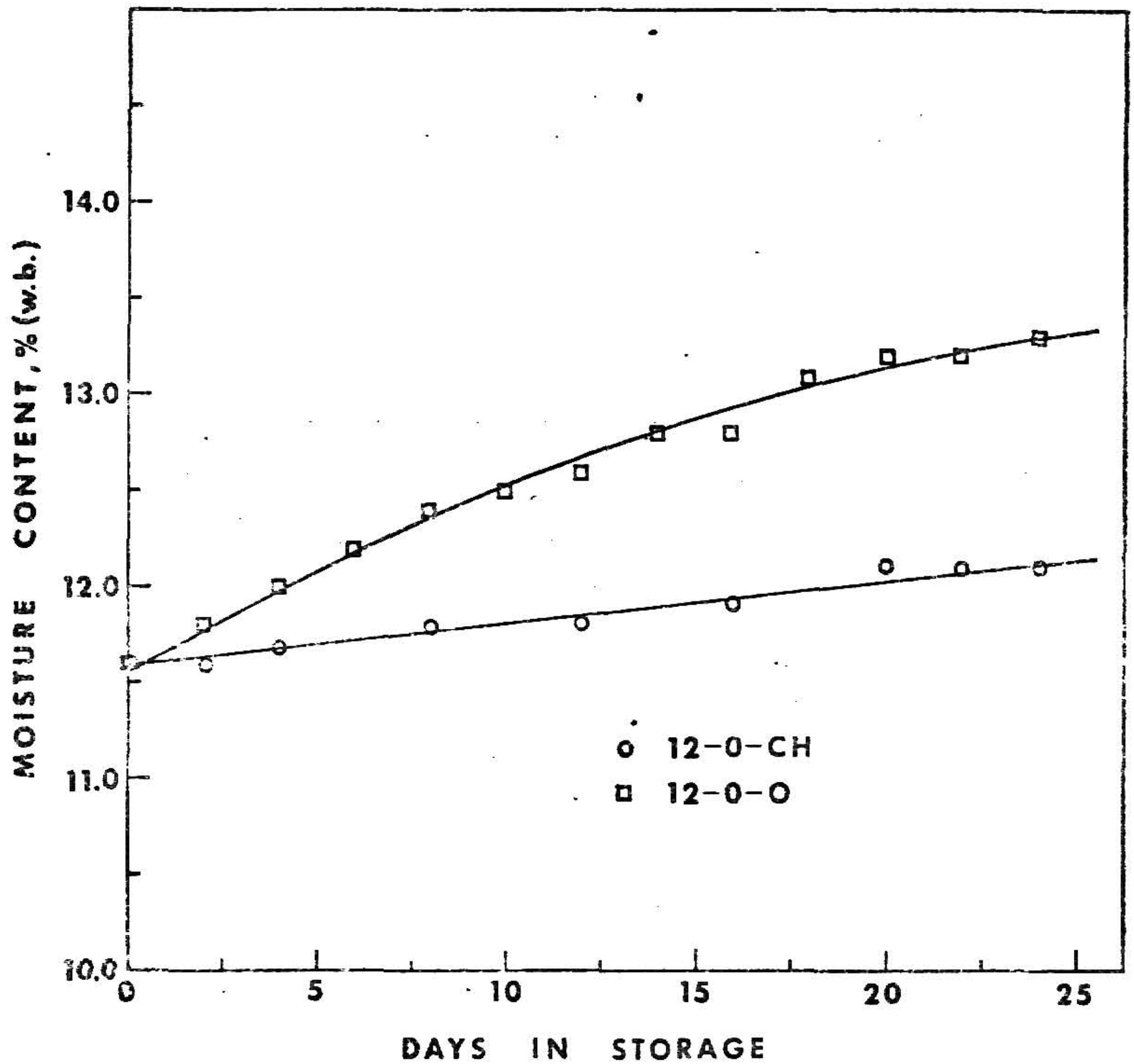


Figure 9. Moisture content versus days in storage for corn samples at 12 percent initial moisture content with no adsorbent present in a closed container with holes and an open container under 95 F and 90–100 percent R.H.

layer of corn sample for all the final series of tests. These were used to slow down the mold growth in the upper layer of corn, which might result from the moisture condensation and a rapid moisture increase by adsorption. In many of the preliminary tests, mold was visible on the top layer of corn in a short storage period.

Since about 70–80% of the adsorptive capacity of silica gel was used up within 24 hours of storage, the frequency of silica gel regeneration was revised for the final series (once every day, once every two days, and once every three days depending on the initial moisture content and storage days), instead of waiting until saturation. The tests showed that the absorptive capacity of silica gel after regeneration at 130 C was higher than that at 100 C. Therefore, in the final series of tests, the silica gel was dried at 130 C for 45 minutes in a laboratory oven.

The data on moisture changes in corn samples and silica gel, grain temperature changes and grain quality change for the final series of tests at various combinations of experimental factors under 95 F and 90–100% R.H. presented in Tables 12 through 21 in the Appendix. The moisture changes during storage for 12% initial moisture corn with only three silica gel sacks on the top layer of samples are shown in Figure 10.

Silica gel was dried once every day for the first week and once every two days thereafter for 12% initial corn in an open can, and once every other day for the first week and once every three days thereafter for 12% initial corn in a closed can. The sample in an open can gained moisture while that in a closed can lost moisture. The sample in an open can gained one-half of one percent in 12½ days while that in a closed can lost slightly more than one-half of one percent in the same length of time. Neither sample showed any visible mold growth at the end of 14 days, but examination results obtained

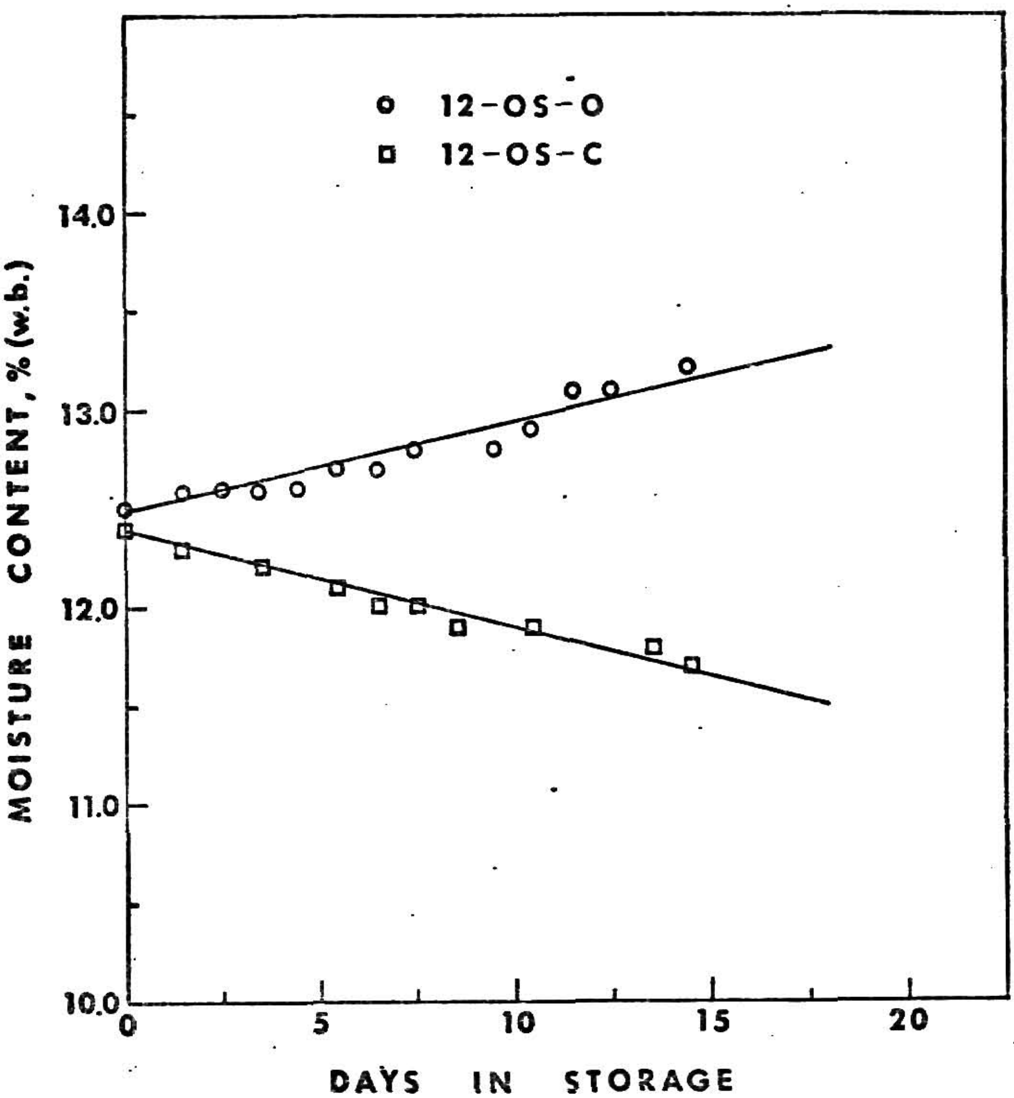


Figure 10. Moisture content versus days in storage for corn samples at 12 percent initial moisture content in closed and open containers with silica gel in three sacks lying on the corn under 95 F and 90-100 percent R.H.

under a microscope (Table 22) showed a few molds. Figure 11 is the plot of mold counts for storage tests of 12% initial moisture corn. The mold development appears to be somewhat more extensive in a closed can than an open can. The germination tests after 14 days storage (Table 22) showed practically no change in germination.

Moisture contents of corn, initially at 15% are shown in Figure 12. Silica gel regeneration was made once every day for the first week and thereafter once every two days for all corn samples at 15% initial moisture content. All four samples show a fast rate of moisture transfer initially, but as the frequency of adsorbent regeneration declines, the drying rate in the two open samples really levels off while that for a closed container does not change as noticeably. Again, none of these samples showed any visible mold development, but the mold assay by a microscope (Table 23) showed some mold development. The mold data plotted in Figure 13 show fluctuating mold counts for the samples at different experimental conditions. However, the mold count in the two open samples at 14 days storage is higher than the closed samples. The two cylinder samples had more mold invasion than the three cylinder cans.

Figure 14 shows grain temperature changes in a typical 15% initial moisture content sample. Whether the can is open or closed, the temperature of the grain was nearly the same in each case. In the 15% samples of Figure 14 the temperature is nearly constant, with a slight decrease as the moisture content decreases, which implies no appreciable mold activity during storage. In addition to the indication of constant grain temperature, no change in germination of the 15% initial moisture samples was observed (Table 23).

Figure 15 shows the rate of drying of the 20% initial moisture content sample. As for the 15% initial moisture content samples, silica gel regeneration was made once every day for the first week and thereafter once every

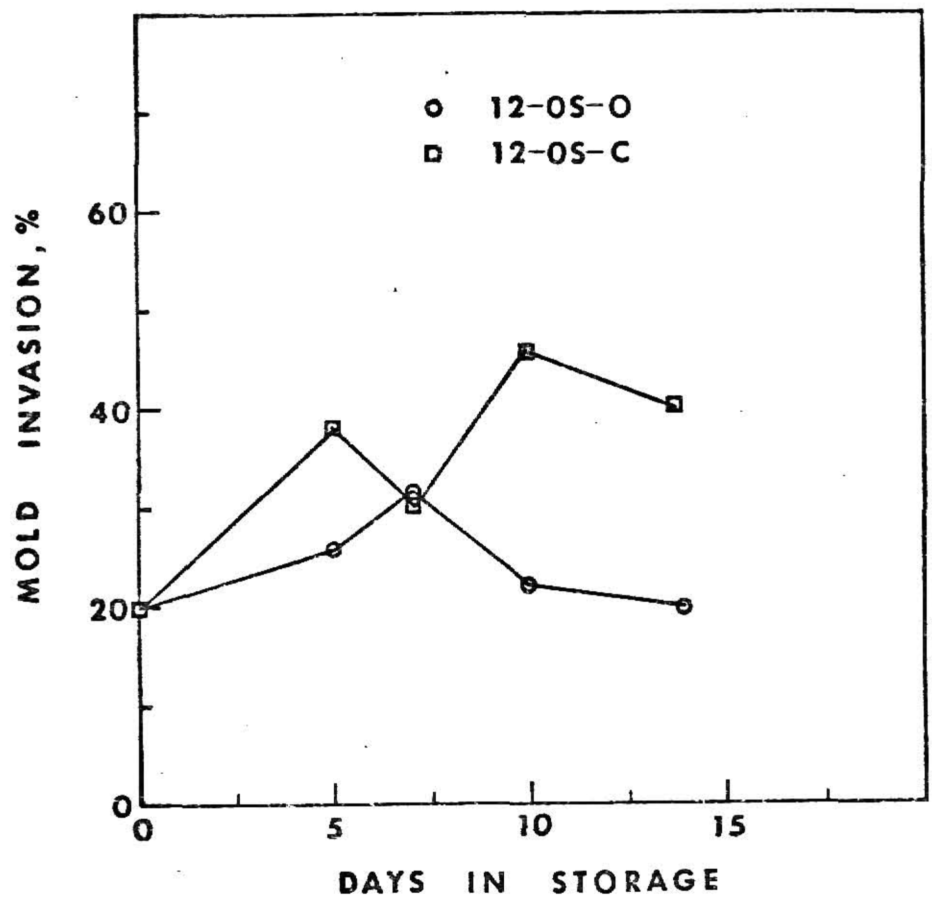


Figure 11. Summation of the percentages of kernels invaded by storage fungi versus days in storage with silica gel for corn samples at 12 percent initial moisture content under 95 F and 90-100 percent R. H.

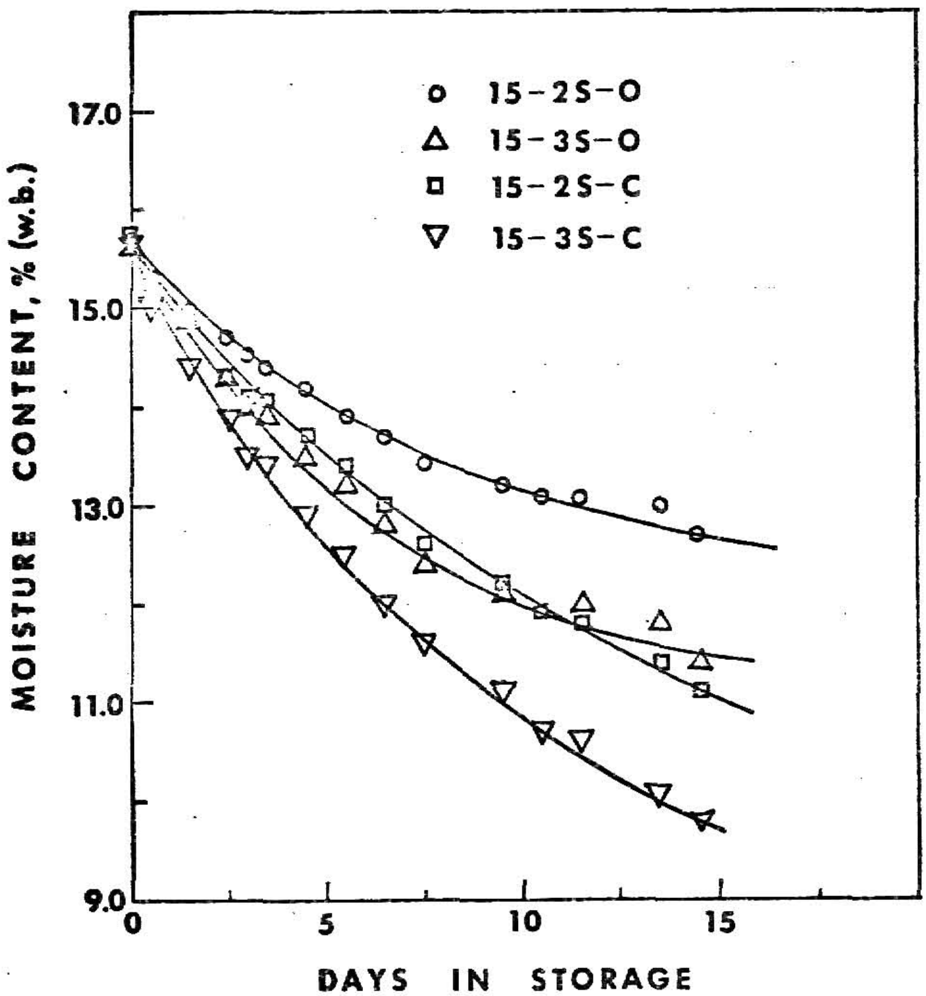


Figure 12. Moisture content versus days in storage for corn samples at 15 percent initial moisture content in closed and open containers with silica gel in two or three cylinders and three sacks lying on the corn under 95 F and 90–100 percent R.H.

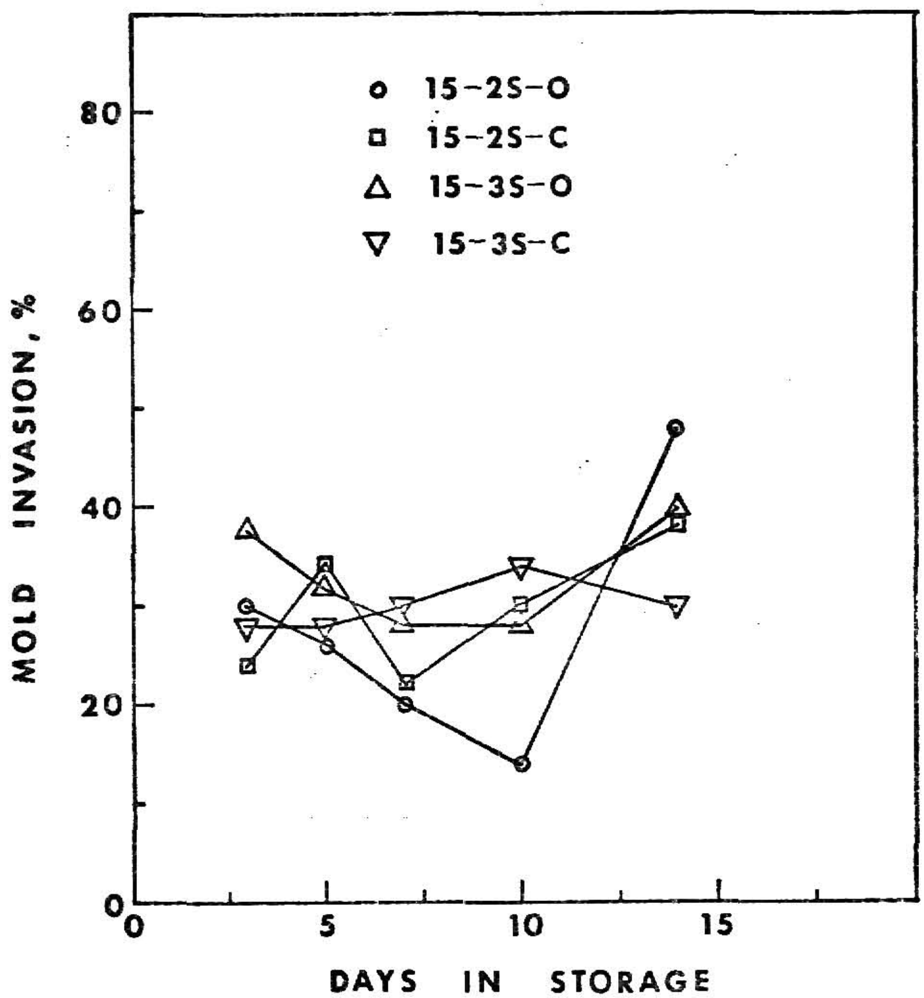


Figure 13. Summation of the percentage of kernels invaded by storage fungi versus days in storage with silica gel for corn samples at 15 percent initial moisture content under 95 F and 90-100 percent R.H.

two days for all corn samples at 20% initial moisture content. The samples in the two open cans indicate a marked decrease in drying rate when the frequency of adsorbent recycling is reduced from once a day to every other day. As the moisture content of corn decreases, the difficulty of moisture removal increases, and the effect of the increased ratio is noticeable. Again, none of the 20% initial moisture content samples showed any visible mold development, but the mold assays of the samples by a microscope (Table 24) indicated the mold growth. The mold invasion for the 20% samples is shown in Figure 16. The samples in an open can exhibit increased mold development with respect to those in closed cans. The three cylinder samples exhibit a greater level of mold development than the four cylinder samples.

Figure 17 shows the grain temperature change in a typical 20% initial moisture content sample under 95 F and 90-100% R.H. environmental condition. Again, as in the 15% cases, whether a can is open or closed, the grain temperature was nearly the same in each case. The grain temperature remained relatively constant throughout the storage period; however, there was a small decrease in temperature as moisture content decreased. The germination tests of the 20% initial moisture content samples showed slight decreases in germination for a few samples.

In Figure 18 the mold invasion due to the possibly harmful fungi (Penicillium and Aspergillus species) are shown for three different initial moisture content samples. The 12% sample shows very little change in development of these species during the storage period while the 15% sample shows a slight increase in these species over the 12% sample. The 20% sample shows a rapid increase of the two species, with these two accounting for more than half of the total storage fungi present on the last day of mold sampling.

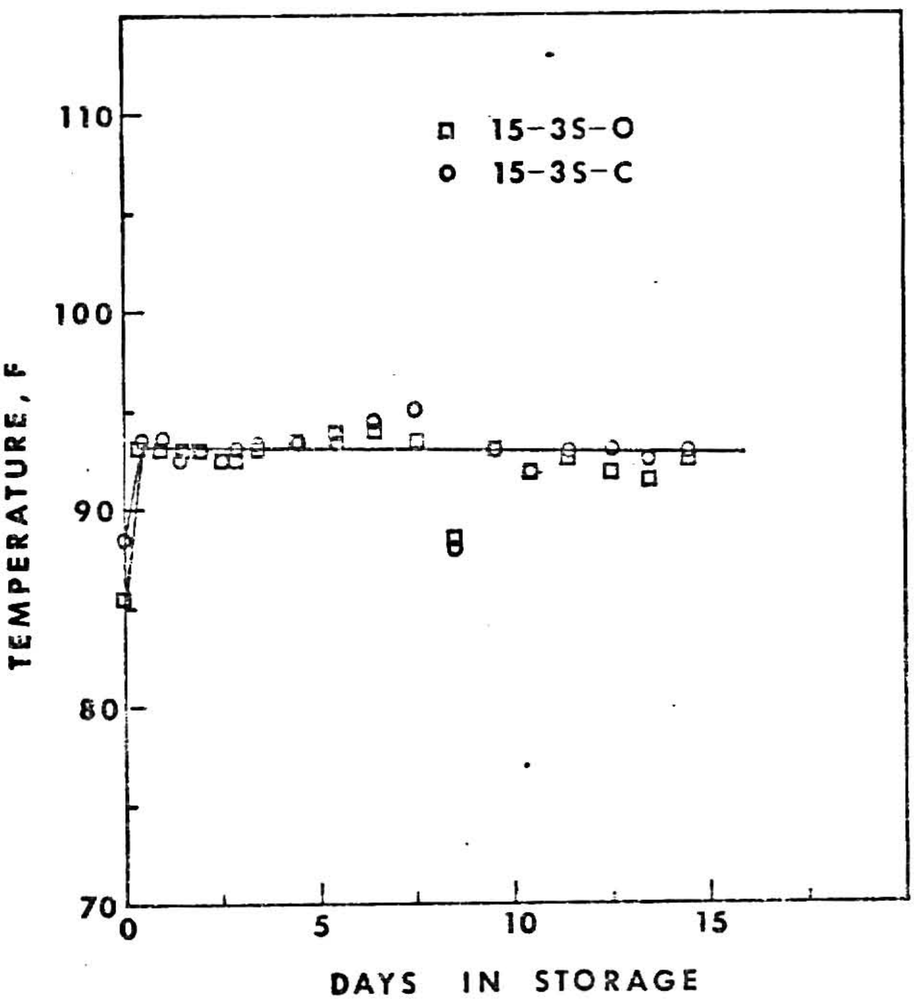


Figure 14. Grain temperature versus days in storage with silica gel for corn samples at 15 percent initial moisture content under 95 F and 90-100 percent R.H.

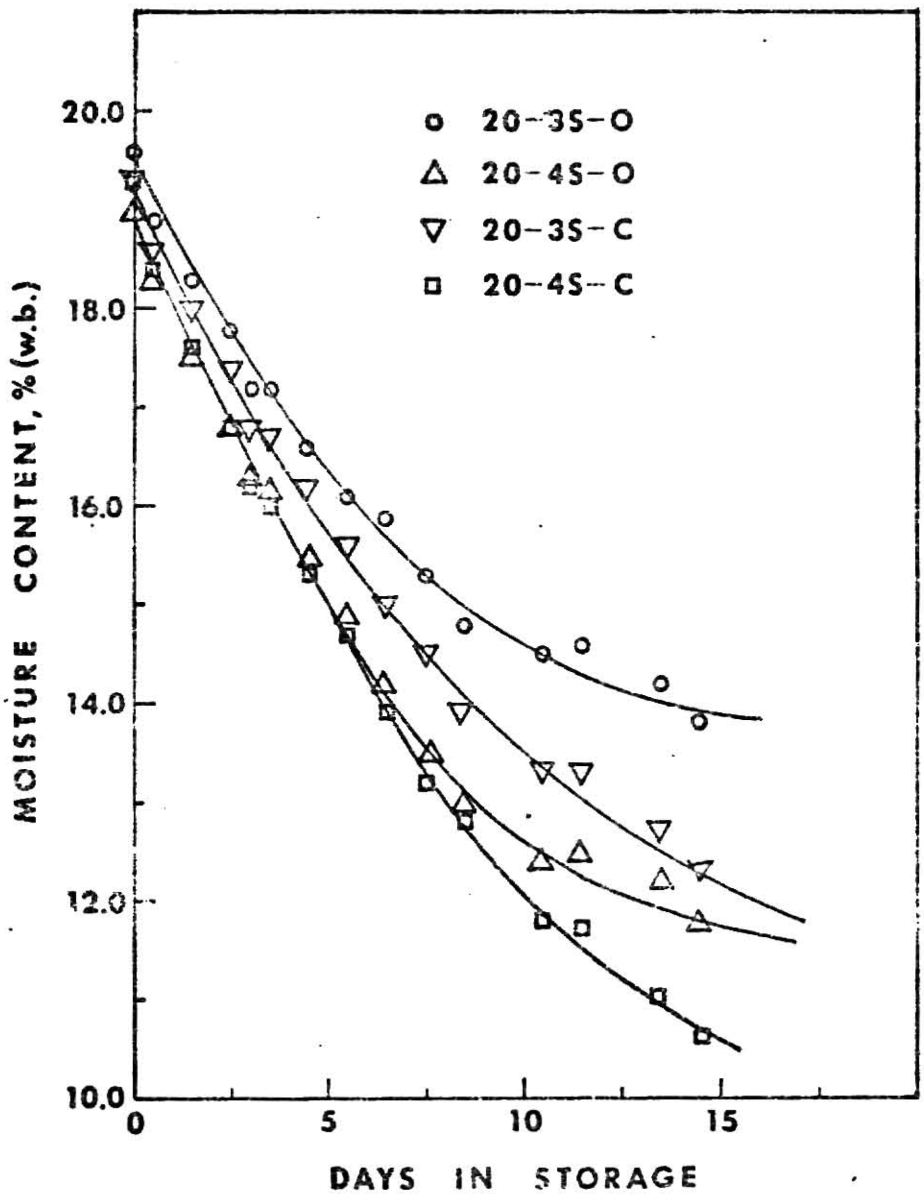


Figure 15. Moisture content versus days in storage for corn samples at 20 percent initial moisture content in closed and open containers with silica gel in three or four cylinders and three sacks lying on the corn under 95 F and 90–100 percent R.H.

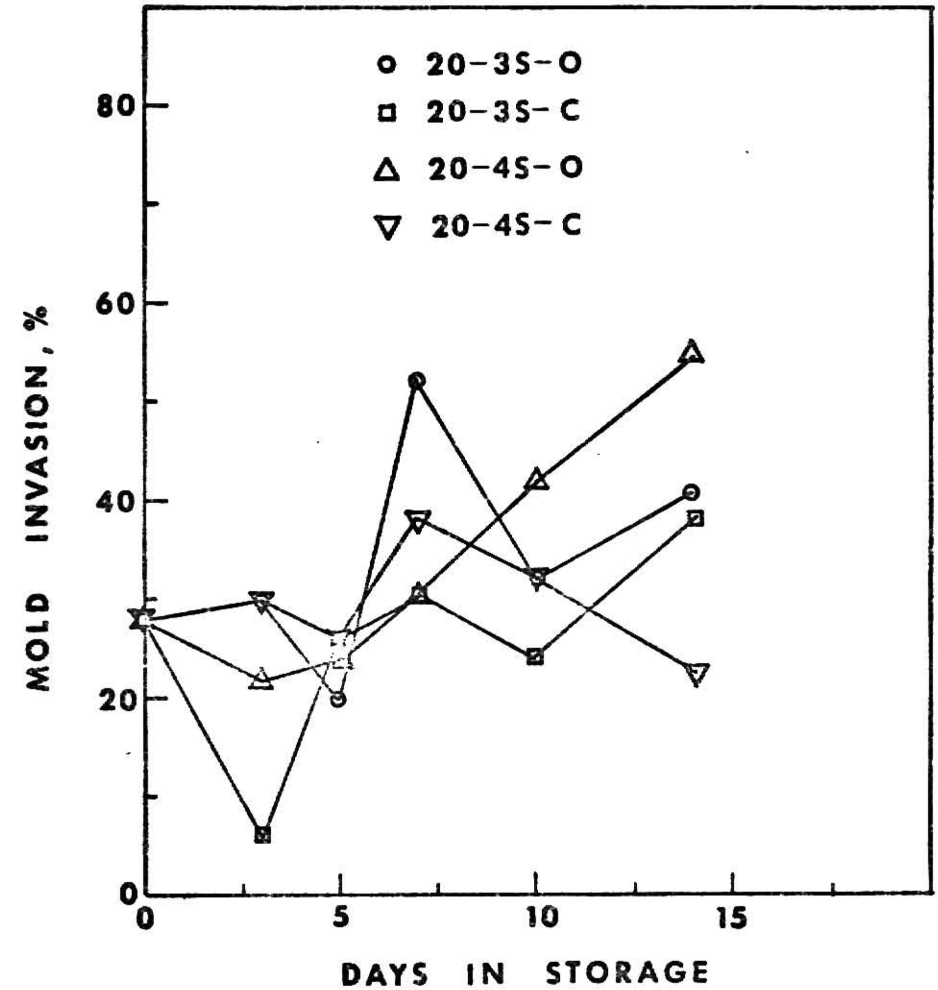


Figure 16. Summation of the percentages of kernels invaded by storage fungi versus days in storage with silica gel for corn samples at 20 percent initial moisture content under 95 F and 90–100 percent R.H.

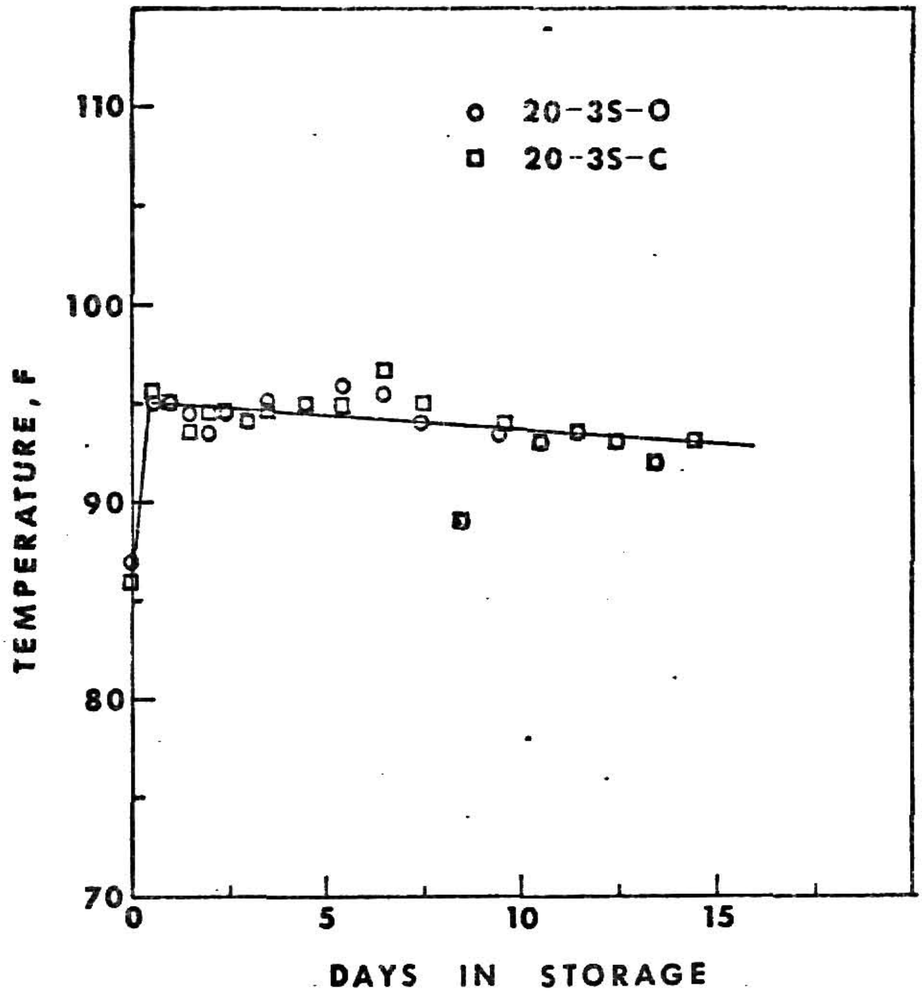


Figure 17. Grain temperature versus days in storage with silica gel for corn samples at 20 percent initial moisture content under 95 F and 90-100 percent R.H.

In reference to mold development, the fungi are listed as field fungi or storage fungi. The Alternaria (Alt.), Fusarium (Fus.), and Cephalosporium (Ceph.) are all field fungi. However, they will grow in storage if the moisture content is greater than 20%. Nigrospora (Nigro.) and Penicillium (Pen.) are classified as field and storage fungi with Nigrospora needing 20% or greater moisture content and Penicillium requiring only 17-18%. Rhizopus (Rhizop.), Mucor (Mucor), Aspergillus Flavus (A. Flav.), and Aspergillus Glacus (A. Glac.) are all strictly storage fungi. The first two require at least 20% moisture content while the Aspergillus Flavus requires only 17-18%. The Aspergillus Glacus will grow readily at 14% and higher moisture contents.

Aspergillus Flavus, an indicator of corn quality, is usually present in the field in less than 2% of the kernels. Levels of invasion may reach as high as 15% for commercial corn. As can be seen in Tables 22 through 24 in the Appendix, most of the samples are well within this 0-15% for A. Flav.

The statistical analysis of the mold data for some of the final series of tests was conducted to study the effects of treatments (combinations of the initial moisture content and the grain to adsorbent ratio), and the condition of container on the mold growth. The data used for the statistical tests are tabulated in Table 25, and the results of statistical tests are given in Table 26 a for the data at 7 days storage. The analysis showed no significant differences in the mold growth between open and closed samples and between various treatments at $\alpha = 0.05$. Evidently some differences on mold counts observed by mold assays for various samples were not statistically significant.

In addition, the statistical analysis of the moisture data for some of the final series of tests was made to study the effect of the grain to adsorbent ratio on the rate of drying. The data used for the statistical

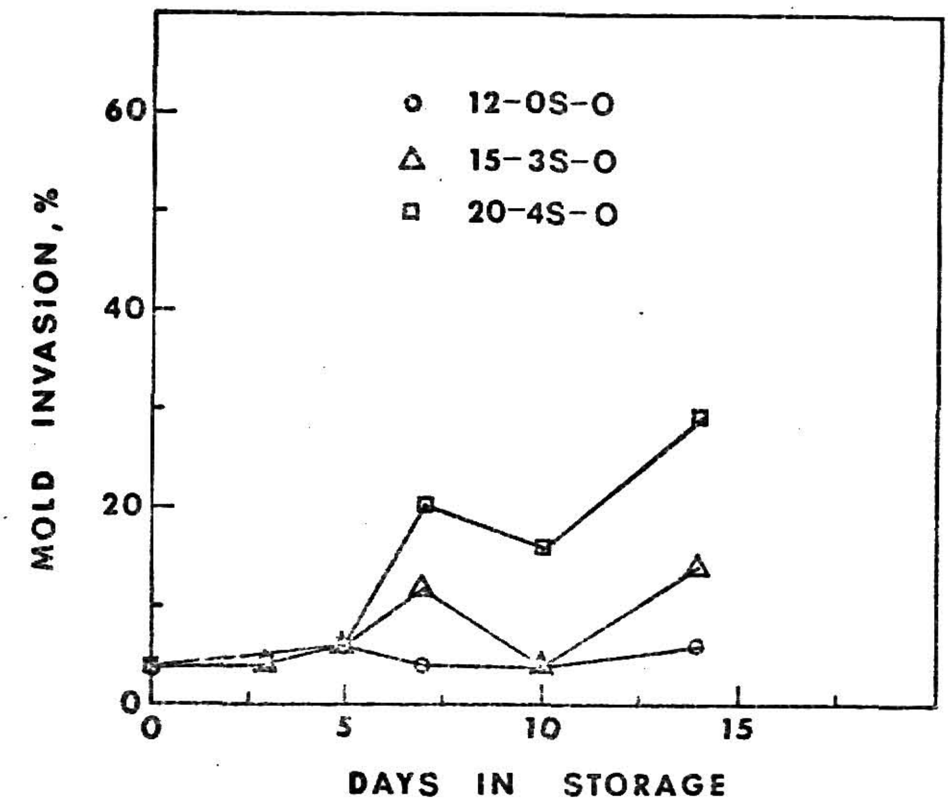


Figure 18. Summation of the percentages of kernels invaded by only penicillium and aspergillus species for three different initial moisture content corn samples under 95 F and 90–100 percent R.H.

analysis and the results of analysis are given in Tables 27 and 28, respectively. The results indicated no significant difference in the rate of drying between open and closed samples, but a significant difference between various grain to adsorbent ratios at $\alpha = 0.05$.

In reviewing the rate of drying and grain quality data for three initial moisture content samples at 95 F and 90–100% R.H., the rate of drying for the 20% initial moisture sample was fast enough to reach a safe storage moisture without any noticeable change in grain quality if the grain to adsorbent ratio was 35:1 and the silica gel was regenerated once every day for a week and thereafter once every two days. For the 15% initial moisture samples, the grain to adsorbent ratio of 50:1 with the same frequency of silica gel regeneration as the 20% cases was adequate to dry and store the corn without visible mold growth. For the 12% initial moisture corn samples, a grain to adsorbent ratio of 140:1 with the frequency of silica gel regeneration at once every day for the first week and thereafter once every three days was adequate to store the corn under 95 F and 90–100% R.H. even if there was continuous moisture leakage into a storage can.

Indeed, the results of grain temperature, the rate of drying, germination tests and visual observation on grain quality, along with the statistical tests of the mold data, supported a definite feasibility of using a drying agent system for drying and storing corn even at extremely adverse storage conditions.

An attempt was made to describe the drying curves for various samples at different grain to silica gel ratios with the frequency of silica gel regeneration applied by the following forms of equations:

$$\frac{M - M_E}{M_O - M_E} = Ae^{-Kt} \qquad (1)$$

Table 25. Mold data (percentages of kernels invaded) at seventh and fourteenth days in storage used in analysis of variance for several samples.

		Treatment				
Day	Condition	12-0S	15-2S	15-3S	20-3S	20-4S
7	open	32	20	28	52	30
	closed	30	22	30	30	38
14	open	20	48	40	41	55
	closed	40	38	30	38	22

Table 26 a. Analysis of variance for mold data at seven days in storage.

Source	Degrees of freedom	Sum of squares	Mean squares	F (calculated)
Treatment	4	425.6	106.4	1.602
Block	1	14.4	14.4	.217
Error	4	265.6	66.4	
Total	9	705.6		

Table 26 b. Analysis of variance for mold data at fourteen days in storage.

Source	Degrees of freedom	Sum of squares	Mean squares	F (calculated)
Treatment	4	194.6	48.65	.2705
Block	1	129.6	129.6	.7206
Error	4	719.4	179.85	
Total	9	1043.6		

Table 27. Moisture content of corn (20 percent initial moisture) at seventh-day in storage used in analysis of variance for testing the effect of corn to silica gel ratios.

Condition	Treatment 50:1	37:1	35:1	30:1
Open	16.9	15.9	15.6	13.8
Closed	17.2	16.2	14.7	13.6

*Drying of adsorbent once per day.

Table 28. Analysis of variance for moisture data at seventh-day in storage.

Day	Source	Degrees of freedom	Sum of squares	Mean squares	F (calculated)
7	Treatment	3	12.13	4.04	25.27*
	Block	1	.03	.03	.1875
	Error	3	.49	.16	
	Total	7	12.65		

*Denotes significance at $\alpha = .05$

where M = moisture content of the sample in percent (w.b.) at time t.

M_E = equilibrium moisture content in percent (w.b.).

M_o = initial moisture content of the sample in percent (w.b.).

A and K = constants.

t = days in storage.

$$Y = ae^{-bt} \tag{2}$$

where Y = moisture content of the sample in percent (w.b.) at time t.

a and b = constants.

The analysis showed that both equations fitted experimental moisture data very well; however, Equation 2 gave a slightly better fit than Equation 1. The constants and correlation coefficients for Equation 1 and Equation 2 are tabulated in Table 29 and Table 30, respectively. From either equation, one can predict the average moisture change during storage at 95 F and 90–100% R.H. for a given initial moisture corn, the grain to silica gel ratios and the frequency of silica gel regeneration.

We attempted a very brief cost analysis for a one-ton unit for using a drying agent-grain drying and storage system based upon projected data from this small study. The results of the cost analysis is shown in Table 31. They indicate that the method proposed would only cost a farmer about $2.68 per ton/year or 6.7¢/bushel/year for drying from 20 to 12% moisture and storing the corn. This analysis was based on a one-ton storage unit figuring no administration or office costs for a small farmer. The total initial investment of silica gel (25¢/lb. for 50 lbs.) plus the wire mesh and sacks amounts to $14.00 for a grain to silica gel ratio of 40:1. The 40 to 1 ratio is based on drying one ton of 20% initial moisture content corn to 12% moisture content and storing it. This ratio would bring the grain to 12% moisture within two weeks if the adsorbent is dried once per day for the first week and once every two days thereafter. A grain to adsorbent ratio of only 140:1 is needed and requires drying once every week.

The one-ton unit was selected, considering a grain yield and grain per capita consumption for an average farm family in humid areas of developing countries. By depreciating the investment over the indicated life span, the yearly depreciation was calculated. A 20 year life span for silica gel was used. It should be noted that silica gel can be regenerated almost infinitely (10,000 times) without reducing its adsorptive capacity appreciably. Actually, silica gel will be regenerated less than 100 times per year. The operating cost did include wages and salaries because it is assumed that the farmer does the work. Also note that the method proposed does not need any utilities, and the maintenance and material costs are minimal. It ~~is~~ also suggested that the farmer will use the heat of his cooking fire to regenerate the silica gel; therefore, no fuel cost is incurred.

No direct comparison could be made with an artificial drying system or other drying and storage systems known because the data are not available in developing countries, and the amount of grain to be dried and stored at the farm in developing countries is too small to justify the use of presently known artificial drying systems. The method developed and its cost analysis, however, do not serve as a recommendation to use this system for drying and storage at this time because the results and analyses were solely on small samples. Much more extensive tests with larger sample sizes must be done before such a recommendation can be made. However, this investigation has shown that the method proposed is technically and economically feasible to use for a small scale.

Table 29. Constants for drying equation of the form, $\frac{M - M_E}{M_o - M_E} = Ae^{-Kt}$

Sample No.*	K	A	Correl. Coeff.
20-3S-0	.1006	1.932	-.881
20-4S-0	.0973	1.683	-.902
20-3S-C	.1040	1.728	-.913
20-4S-C	.1130	1.915	-.904
14-2S-0	.0288	1.109	-.946
15-3S-0	.0388	1.168	-.936
15-2S-C	.041	1.120	-.970
15-3S-C	.047	1.168	-.958
12-0S-0	-.0061	1.007	.959
12-0S-C	.0053	1.006	-.982
12-0-0	-.0087	.988	.991

*M_E = 20.68%

All moisture contents are wet basis.

Table 30. Constants for drying equation of the form, $Y = ae^{-bt}$

Sample No.	b	a	Correl. Coeff.
20-3S-0	.0230	18.73	-.973
20-4S-0	.0330	18.15	-.978
20-3S-C	.0305	18.66	-.990
20-4S-C	.0413	18.57	-.994
15-2S-0	.0135	15.20	-.969
15-3S-0	.0210	15.08	-.970
15-2S-C	.0230	15.29	-.993
15-3S-C	.0310	15.01	-.992
12-0S-0	-.0037	12.46	.962
12-0S-C	.0038	12.36	-.984
12-0-0	-.005	11.74	.986

All moisture contents are wet basis.

Table 31. Estimated cost analysis for drying and storage of one-ton unit of corn at 20 percent m.c. initially by using silica gel as a drying agent.

I.	Fixed Costs		
	A. Administration		$ .00
	B. Office Costs		.00
	C. Depreciation		
	1) Invest		@ .25/lb.
	Silica gel (50 lbs)		12.50
	Wire (mesh)		1.00
	Sack		.50
			$14.00
	Silica gel: straight line depreciation of 20 years		0.63/year
	Wire (mesh): straight line depreciation of 5 years		.20/year
	Sack: straight line depreciation of 2 years		.25/year
			$ 1.08/year
	D. Interest: 10% per annum $14.00(.1) = 1.40		1.40
		Sub-total	$ 2.48/ton/year
II.	Operating Cost		
	A. Wages and Salaries		$ .00
	B. Utilities		.00
	C. Repairs and Maintenance		.20
	D. Supplies and Materials		.00
		Sub-total	.20/ton/year
		TOTAL	$ 2.68/ton/year

If the method proposed could prove to be workable for a larger scale (i.e. one-ton unit), then it has many advantages over presently available methods. Silica gel is inert to the grain; thus, there is no danger of consuming it by humans; and it can be regenerated almost infinitely. The initial capital investment and the operating costs are very small. No utilities or skilled persons are needed. There is no handling of the grain once it is placed in a storage unit, thus less chance of damaging the grain. Also the drying rate is slow and steady with no high temperature involved. Therefore, the stress cracks should be at a minimum, resulting in better grain quality for ultimate uses (Foster, 1964). The grain does not have to be recycled for redrying, which is common in humid regions. Indeed, the method proposed would have a potential to be used on a small farm in humid regions where presently available methods cannot be readily applied because of economic and climatic conditions.

CONCLUSIONS

From the results of this investigation the following conclusions were drawn:

1. Of various drying agents tested, silica gel was the only one that may be effectively used for drying and storing corn in humid areas.
2. The rate of drying was greatly affected by the grain to adsorbent ratio (the lower the ratio, the higher the rate), and decreased as the moisture content of grain decreased.
3. The frequency of silica gel regeneration greatly affected the rate of drying.
4. The rate of drying was also affected by the condition of a storage container. The rate was faster for a container with the lid closed than with the lid opened.
5. The rate of drying for the samples stored in high temperature and high relative humidity conditions followed the form of equation

$$\frac{M - M_E}{M_o - M_E} = Ae^{-Kt}$$

6. The rate of water adsorption by silica gel was very high at an initial stage of storage and then sharply decreased. It depended on the initial moisture content of corn stored, but generally about 70 percent of adsorptive capacity of silica gel was used up within 24 hours after placing it into a storage container under test conditions.
7. Adequate drying and storage of clean grain in small quantities at the initial moisture content below 20% under extremely humid conditions can be accomplished by the proper use of silica gel as follows:

Initial moisture content of 12%

1) Place silica gel in three nylon sacks on the top layer of grain (the grain to silica gel ratio = 140:1).

2) Regenerate (dry) silica gel once every three days at approximately 130 C for 45 minutes if a storage container has many leakages, and if not, regenerate it once every week.

Initial moisture content of 15%

1) Place silica gel in two cylinders and in three small sacks on the top layer of grain (the grain to silica gel ratio = 50:1).

2) Regenerate silica gel once every day for the first seven days of storage and thereafter every other day for another week. At this point the grain would be at a safe moisture content for storage. Thus, from then on follow the procedure for 12% moisture corn.

Initial moisture content of 20%

1) Place silica gel in three cylinders and three small sacks on the top layer of grain (the grain to silica gel ratio = 35:1).

2) Regenerate silica gel once every day for the first seven days of storage and thereafter every other day for another week. At this point the grain would be at a safe moisture content for storage. Thus, from then on follow the procedure for 12% moisture corn.

8. Tests under the above procedures showed no change in grain temperature and no visible mold development on grain. Also, practically no change in germination was observed. However, mold count assays under a microscope revealed various species of molds on grain samples tested. Though the differences in mold counts on the different initial moisture content samples at various storage periods were observed (higher mold counts on higher initial moisture content samples), these differences

were not statistically significant and these changes in grain quality observed during storage would not lower the grain grade.

9. A cost analysis on a one-ton storage unit by the method developed in this investigation showed that the drying and storage cost is about $2.68/ton/year or 7 cents/bushel/year (drying 20% moisture to 12% moisture).

10. The use of silica gel for grain drying and storage has many advantages over other conventional and non-conventional methods. Practically no initial capital investment (only cost of silica gel) and utilities, or skilled persons are needed. This method has technical and economic feasibility for small scale, on-farm storage in humid areas where the present non-conventional and conventional methods cannot be readily used because of climatic and economic conditions. Silica gel is completely inert to the grain and can be infinitely regenerated (10,000 times, without appreciable loss of adsorptive potential under 600 F). No handling of grain is needed for conditioning the grain after placing it in a storage unit. Therefore, minimum physical damage to grain can be expected. In addition, a better physical quality of grain (minimum stress cracks) can be expected due to no heat and slow drying.

SUGGESTIONS FOR FUTURE WORK

The following suggestions are recommended for future work:

1. Rerun the last series of tests to see if they are repeatable.
2. Study corn samples at a higher initial moisture content (23-24% M.C.) to find an effective ratio of grain quantity to silica gel quantity for preserving a grain quality.
3. Study the effect of initial grain conditions on drying and storage characteristics by using silica gel as a drying agent.
4. Test other grains for preserving grain quality by a drying agent.
5. Conduct the same experiments with larger sizes of samples to examine whether the methods established in small scale tests can be used for significantly larger storage units.
6. Search for cheaper adsorbents which can be used for grain drying and storage.
7. Test a drying agent system with air movement within a storage unit.
8. Develop an effective and inexpensive storage unit by testing several shapes of storage units constructed with different construction materials.
9. Conduct a detailed economic analysis of new units and methods by considering all marketing alternatives, currently available units, and methods.
10. Conduct field tests with a recommended storage unit and method at selected humid areas in developing countries.

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APPENDIX

Table 2. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in a closed container with silica gel in 1 cylinder (12-1-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	4116.0	0	79.5	.126	Initial adsorbent wt.- 22.59 g.
.5	4114.5	3.69	91.0		Desiccant at saturation dried at 100 C for 1 hour.
1.0	4112.0	2.16	92.0		
1.5	4112.0	.81	93.0		
2.0	4111.5	.40	93.0		
2.5	4111.5	.17	94.0		
3.0	4110.0	1.96	93.0	.125	
3.5	4109.5	.72	93.0		
4.0	4109.5	.25	92.0		
4.5	4109.5	.10	93.0		
5.0	4107.0	2.94	93.0	.124	
5.5	4106.5	1.14	94.0		
6.0	4105.5	.53	93.0		
6.5	4105.0	.24	94.5		
7.0	4105.5	.12	93.0		
8.0	4102.5	4.47	92.5	.123	
9.0	4101.5	.79	93.0		
10.0	4101.0	.27	92.0		
11.0	4098.0	4.21	93.0	.122	
12.0	4098.0	.84	94.0		
13.0	4098.0	.25	94.0		

Table 2. (Con't.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
14.0	4094.5	3.82	94.0	.121	
15.0	4094.0	.72	94.5		
16.0	4093.0	.23	94.0		
17.0	4088.5	4.32	94.5	.120	
18.0	4088.5	.86	94.5		
20.0	4083.5	4.43	98.0	.119	
22.0	4084.0	.93	96.5		
24.0	4079.0	4.73	98.0	.118	
26.0	4074.0	4.51	94.0	.117	No mold. Good odor

[1]Initial silica gel to corn ratio of 1:185. Corn purchased at local elevator.

Table 3. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in an open container with silica gel in 1 cylinder (12-1-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of Adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	4026.0	0	76.0	.123	Initial adsorbent wt.- 21.20 g. Desiccant at saturation dried at 95 C for 1 hour.
.5	4031.0	3.33	89.5		
1.0	4032.5	1.30	89.5		
1.5	4035.5	.54	91.0		
2.0	4037.0	.20	90.0		
2.5	4039.0	.10	94.0		
3.0	4041.5	.05	93.0		
3.5	4041.5	3.46	93.0	.126	
4.0	4042.0	1.12	92.0		
4.5	4045.0	.42	95.0		
5.0	4047.5	.17	95.0		
5.5	4049.5	.09	96.0		
6.0	4048.0	3.60	95.0	.128	
6.5	4048.5	.93	97.5	.128	
7.0	4049.5	.36	95.0		
8.0	4050.0	4.64	94.0	.128	
9.0	4052.5	.52	97.0		
10.0	4054.0	3.65	96.0	.129	
11.0	4055.0	1.17	96.0		
12.0	4058.0	.22	93.0	.130	
13.0	4057.0	3.38	95.5	.130	Several small spots of mold.

Table 3. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
14.0	4055.0	1.27	95.5		
15.0	4055.5	.23	98.0		
16.0	4050.5	4.19	98.5	.129	
17.0	4050.5	.45	95.0		
18.0	4048.0	3.27	95.5	.128	Mold increasing very slowly.
20.0	4047.0	.24	94.5		
22.0	4044.5	4.82	95.0		
24.0	4041.5	4.08	93.0	.127	
26.0	4040.5	3.70	93.0	.126	

[1] Initial silica gel to corn ratio of 1:190. Corn purchased at local elevator.

Table 4. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in an open container with silica gel in 1 cylinder (15-1-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	3937.5	0	57.5	.158	Initial adsorbent wt.- 24.56 g. Desiccant at saturation dried at 95 C for 1 hour.
.5	3938.5	4.94	89.5		
1.0	3938.0	1.97	90.0		
1.5	3939.5	.23	91.5		
2.0	3942.5	.08	90.0	.159	
2.5	3937.0	5.03	93.5	.158	
3.0	3936.5	1.15	92.0		
3.5	3938.0	.15	93.0		
4.0	3940.5	.06	92.0	.159	
4.5	3938.0	4.53	95.0	.158	
5.0	3937.5	.81	95.0		
5.5	3939.5	.08	97.0	.158	
6.0	3935.5	4.81	95.5	.158	Mold starting to form on broken kernels.
6.5	3936.5	.97	97.0		
7.0	3936.5	.16	95.5	.158	
7.5	3932.5	4.99	95.5	.157	
8.0	3932.5	.90	94.5		
8.5	3933.0	.15	95.5		
9.0	3933.0	.02	94.5	.157	
9.5	3928.5	4.90	98.0	.156	No odor, several large spots of mold.
10.0	3928.5	1.18	96.0		
10.0	3929.0	.10	98.0		

Table 4. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
11.0	3928.5	.01	96.0	.156	
11.5	3924.5	4.74	95.0	.155	
12.0	3926.5	1.02	94.0		
12.5	3922.5	.20	95.5	.155	
13.0	3920.5	4.52	96.5	.154	Starting to get musty. Bottom layer of can not mold, most kernels have been invaded.

[1]Initial silica gel to corn ratio of 1:160. Corn purchased at local elevator. Water added to reach initial moisture content.

Table 5. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in an open container with silica gel in 2 cylinders (15-2-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	3743.0	0	62.0	.153	Initial adsorbent wt.- 41.27 g. Desiccant at saturation dried at 100 C for 1 hour.
.5	3742.5	11.59	92.0		
1.0	3741.0	.78	92.0		
1.5	3740.0	.09	92.0		
2.0	3729.5	10.43	92.5	.147	
2.5	3728.5	.91	92.5		
3.0	3727.0	.10	93.0		
4.0	3714.5	11.48	93.0	.144	
4.5	3713.5	.11	93.0		
5.0	3704.5	9.73	92.5		
5.5	3704.5	1.59	92.5		
6.0	3704.0	.20	93.0	.142	
6.5	3704.0	.00	92.5		
7.0	3695.5	9.93	93.0		
8.0	3695.0	1.99	93.0	.140	
9.0	3684.5	11.58	93.0		Mold on the ends of a few kernels.
10.0	3679.0	9.05	93.0	.136	
11.0	3673.5	3.13	92.5		
12.0	3674.0	.19	92.5	.135	
13.0	3668.5	9.46	92.0	.133	

Table 5. (Con't.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
14.0	3669.0	2.20	93.0	.133	
15.0	3665.5	9.03	93.0		
16.0	3667.5	2.24	92.0	.133	
17.0	3671.5	.16	92.0		
18.0	3673.0	.02	93.0	.134	
19.0	3663.0	11.36	92.5		Couple of mold spots.
20.0	3657.0	2.61	93.0	.131	Not really any increase.
21.0	3651.0	10.77	92.0		
22.0	3651.5	.44	91.5	.129	

[1]Initial silica gel to corn ratio of 1:91. Corn purchased at local elevator. Water added to reach initial moisture content.

Table 6. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in an open container with silica gel in 3 cylinders (15-3-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	3836.0	0	69.0	.152	Initial adsorbent wt.- 72.66 g. Sample mixed previous day. Stored at 50 F.
.5	3823.5	13.49	94.0		Desiccant at saturation dried at 95 C for 1 hour.
1.0	3814.5	8.12	98.5		
1.5	3813.5	.43	96.5		
2.0	3813.5	.17	96.0		
2.5	3796.5	15.79	97.0	.143	
3.0	3793.5	3.51	96.0		
3.5	3793.0	.23	97.0		
4.0	3777.5	15.61	95.5	.139	
4.5	3774.5	3.02	97.0		
5.0	3774.5	.31	94.0		
5.5	3759.5	13.82	95.0	.135	
6.0	3756.5	4.15	94.0	.134	
6.5	3956.0	.67	96.0		
7.0	3743.5	13.35	95.5	.131	
8.0	3740.5	3.78	95.0		
9.0	3725.5	16.06	93.0	.128	
10.0	3725.0	1.38	93.5		
11.0	3714.0	12.34	93.0	.124	
12.0	3710.5	3.86	94.0		
13.0	3711.0	.36	94.0		

Table 6. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
14.0	3697.0	15.31	93.5	.121	
15.0	3694.5	1.50	92.5		
16.0	3695.5	—	91.5	.120	
17.0	3685.0	15.34	89.0	.118	
18.0	3683.0	2.61	93.0		
19.0	3682.5	.38	92.5		
20.0	3668.0	15.21	93.5	.114	
21.0	3671.5	2.22	94.0		No mold visible.

[1]Initial silica gel to corn ratio of 1:52.5. Corn purchased at local elevator, water added to reach initial moisture content.

Table 7. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in an open container with silica gel in 1 cylinder (20-1-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase of weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Remarks
0	3876.75	0	64.0	.198	Initial adsorbent wt.- 25.40 g.
.5	3875.75	6.82	88.5		Desiccant at saturation dried
1.0	3873.25	.89	90.5		at 95 C for approx. 1 hour.
1.5	3872.75	.06	93.5		
2.0	3872.75	.01	91.0	.197	First sign of mold.
2.5	3865.75	6.41	95.5	.196	
3.0	3864.25	.29	92.5		
3.5	3863.75	.08	94.0		
4.0	3862.75	.04	93.5	.195	
4.5	3857.75	5.56	97.0	.194	
5.0	3856.25	.20	96.0		
5.5	3855.25	.05	97.5	.194	Isolated mold spots increasing.
6.0	3848.00	5.97	96.5	.192	
6.5	3847.25	.26	98.5		
7.0	3845.75	.04	96.5	.192	
7.5	3839.00	6.16	97.5	.190	
8.0	3837.25	.26	95.0		
8.5	3837.75	.01	97.5	.190	
9.0	3830.75	5.82	97.0	.188	
9.5	3829.75	.66	99.5		Several large moldy spots, musty odor.
10.0	3828.25	.04	98.0	.188	When sample taken out, moldy throughout.

[1]Corn purchased at local Co-op, mixed with water to increase moisture content, stored in cooler at 50 C. Initial silica gel to corn ratio of 1:153.

Table 8. **Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in an open container with silica gel in 3 cylinders (20-3-0) at 95 F and 90-100 percent R.H.**[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Remarks
0	3772.50	0	69.0	.197	Initial adsorbent wt.- 72.82 g. Desiccant at saturation dried at 95 C for 1 hour.
.5	3749.50	21.21	98.5		
1.0	3745.00	.51	97.5		
1.5	3741.50	.12	96.5		
2.0	3721.00	19.11	99.0	.185	
2.5	3718.50	.88	97.0		Couple of small spots of mold.
3.0	3717.00	.10	99.0		
3.5	3696.00	18.41	98.0	.180	
4.0	3693.50	.54	99.5		
4.5	3689.50	.13	98.0		
5.0	3669.00	18.90	99.0	.174	
5.5	3666.00	1.22	98.0		
6.0	3663.50	.12	96.0	.173	
6.5	3643.50	17.39	100.5	.168	
7.0	3640.50	.62	103.0		
7.5	3637.50	.12	102.0		
8.0	3618.00	17.72	98.0	.162	Mold increasing slowly.
8.5	3614.00	1.29	98.5		
9.0	3613.00	.14	99.0		
10.0	3593.00	17.26	99.0	.156	
11.0	3587.00	2.00	100.0		Moldy odor, rapid increase of mold.
12.0	3566.75	16.51	100.0	.150	

Table 8. (Cont'd.)

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Remarks
13.0	3561.00	1.76	99.5		
14.0	3539.50	17.49			
16.0	3515.50	--	94.0	.138	
18.0	3504.00	4.47	99.0		
20.0	3478.00	18.49	95.0		

[1]Initial silica gel to corn ratio of 1:52. Corn purchased at local elevator, water added to reach initial moisture.

Table 9. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in an open container with silica gel in 4 cylinders (20-4-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content	Remarks
0	3641.0	0	61.5	.200	Initial adsorbent wt.- 84.63 g.
.5	3622.5	19.69	86.0		Desiccant at saturation dried
1.0	3616.0	6.30	90.0	.194	at 100 C for 1 hour.
1.5	3614.0	.28	93.5		
2.0	3612.5	.16	93.0	.194	
2.5	3610.5	.05	90.0		
3.0	3584.5	24.72	94.0	.187	Mold formation starting.
4.0	3580.5	.78	95.0		
4.5	3577.5	.09	97.0	.186	Mold rapidly increasing.
5.0	3555.0	22.87	96.0	.181	

[1] Initial silica gel to corn ratio of 1:43. Corn mixed with water to increase M.C. to 20%, stored at 50 F for 1 week or so until used.

Table 10. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in an open container with no adsorbent present (12-0-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Temperature (F)	Moisture content	Remarks
0	3967.0	77.0	.116	
.5	3969.0	88.0		
1.0	3971.0	91.0		
1.5	3974.0	91.5		
2.0	3976.0	90.0	.118	
2.5	3978.0	91.5		
3.0	3981.5	91.0		
3.5	3984.0	91.5		
4.0	3985.5	90.5	.120	
5.0	3989.5	92.0		
6.0	3993.5	92.5	.122	
7.0	3998.0	93.0		
8.0	4001.0	93.5	.124	Initial signs of mold.
9.0	4004.5	93.0		
10.0	4006.0	93.0	.125	
11.0	4009.0	93.0		
12.0	4012.0	93.5	.126	
13.0	4015.0	93.0		
14.0	4019.5	93.0	.128	
15.0	4022.5	92.5		
16.0	4023.5	92.0	.128	
17.0	4027.0	91.0		
18.0	4035.0	91.0	.131	
19.0	4039.0	91.0		
20.0	4040.0	92.0	.137	

Table 10. (Cont'd.)

Days in storage	Weight of grain (grams)	Temperature (F)	Moisture content	Remarks
21.0	4040.5	92.0		Mold increasing rapidly. Present on all upper layer.
22.0	4042.0	92.0	.132	
23.0	4045.5	92.5		
24.0	4046.0	91.5	.133	
25.0	4047.5	91.0		

[1]Corn purchased at local elevator.

Table 11. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in a closed container[1] having 3 holes in the side with no adsorbent present (12-O-CH) at 95 F and 90-100 percent R.H.

Days in storage	Weight of grain (grams)	Temperature (F)	Moisture content	Remarks
0	3981.5	77.0	.116	
.5	3982.0	88.0		
1.0	3982.0	90.0		
1.5	3982.0	90.5		
2.0	3982.5	89.0	.116	
2.5	3983.0	91.5		
3.0	3984.0	90.5		
4.0	3985.5	92.0	.117	
5.0	3987.5	92.5		
6.0	3988.0	92.5		
7.0	3989.0	92.5		
8.0	3990.5	92.5	.118	
9.0	3990.0	93.5		
10.0	3992.0	93.0		
11.0	3992.0	92.5		
12.0	3992.5	93.5	.118	
13.0	3994.5	93.5		
14.0	3995.5	93.5		
15.0	3997.0	92.5		
16.0	3997.0	92.0	.119	
17.0	3999.0	91.5		
18.0	3999.0	91.0		
19.0	4002.0	90.0		
20.0	4002.0	91.5	.121	
21.0	4002.0	92.0		

Table 11. (Cont'd.)

Days in storage	Weight of grain (grams)	Temperature (F)	Moisture content	Remarks
22.0	4003.0	92.0	.121	
23.0	4003.5	92.0		
24.0	4005.0	92.0	.121	
25.0	4006.0	92.0		No mold.

[1]Corn purchased at local elevator.

Table 12. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in an open container without cylinders and with silica gel in 3 sacks (12-OS-O) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3695.5	0	101.5	.125	.116	Initial adsorbent wt.- 25.85 g.
.5	3694.5	4.70	93.5			
1.0	3695.5	1.78	91.0			
1.5	3697.5	.25	90.5	.126		Desiccant dried every day at 130 C after this day.
2.0	3697.5	4.55	88.5			
2.5	3699.5	1.23	90.0	.126		
3.0	3699.0	5.13	90.0			
3.5	3700.5	.81	90.5	.126		
4.5	3700.5	5.82	91.0	.126		
5.5	3702.0	5.95	93.0	.127	.123	57.37 g. sample taken for analyses.
6.5	3647.5	5.80	94.5	.127		
7.5	3649.0	6.42	91.0	.128	.125	63.10 g. sample taken, desiccant dried every 2 days after this day.
8.5	3586.0	5.75	89.5			
9.5	3588.5	.19	91.0	.128		
10.5	3591.5	5.64	89.0	.129	.127	62.10 g sample taken for analysis.
11.5	3536.5	.13	91.0	.131		
12.5	3537.5	5.99	90.0	.131		
13.5	3540.5	.04	89.0			
14.5	3540.5	5.56	90.0	.132	.122, .123	Sample taken. No mold visible.

[1] Initial silica gel to corn ratio of 1:143. Newly harvested corn dried to initial moisture content.

Table 13. Grain weight, temperature, and moisture changes during storage period for 12 percent M.C. corn stored in a closed container without cylinders and with silica gel in 3 sacks (12-OS-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3663.0	0	101.5	.124	.116	Initial adsorbent wt.- 26.16 g.
.5	3659.5	3.40	93.0			
1.0	3657.5	1.62	91.0			
1.5	3657.0	.53	90.5	.123		Desiccant dried every 2 days after this day at 130 C.
2.0	3654.5	2.85	88.5			
2.5	3653.0	1.43	89.5			
3.0	3653.0	.66	89.5			
3.5	3653.0	.25	91.0	.122		
4.5	3649.5	3.59	90.5			
5.5	3648.5	1.25	92.0	.121	.108	59.83 g. sample taken for analyses.
6.5	3587.5	3.68	94.0	.120		
7.5	3586.0	.97	90.0	.120	.106	50.07 g. sample taken, desiccant dried every 3 days after this day.
8.5	3519.5	3.61	90.0	.119		
9.5	3520.0	.77	90.0			
10.5	3519.5	.44	88.0	.119	.106	65.42 g. sample taken for analyses.
11.5	3450.0	4.19	89.5			
12.5	3448.5	1.12	89.0			
13.5	3449.0	.41	87.5	.118		
14.5	3446.0	3.24	88.0	.117	.109, .111	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:140. Newly harvested corn dried to initial moisture content.

Table 14. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in an open container with silica gel in 2 cylinders and 3 sacks (15-3S-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3515.0	0	86.5	.157		Initial adsorbent wt.- 66.58 g.
.5	3498.0	18.06	92.0	.153		Desiccant dried every day at
1.0	3486.5	14.93	93.5			130 C.
1.5	3487.0	1.69	93.0	.150		
2.0	3476.0	13.50	93.0			
2.5	3475.5	2.88	93.0	.147		
3.0	3464.0	13.74	93.0	.145	.141	61.11 g. sample taken for ana-
3.5	3401.5	2.55	93.0	.144		lyses.
4.5	3393.5	16.16	92.5	.142		
5.5	3382.5	15.90	93.5	.139	.130	59.5 g. sample taken for analy-
6.5	3313.0	16.89	94.0	.137		ses.
7.5	3303.5	16.96	93.5	.134	.125	60.68 g. sample taken, desiccant
8.5	3234.0	16.42	86.5			dried every 2 days after this
9.5	3236.5	.99	93.0	.132		day.
10.5	3230.0	16.37	91.0	.131	.129	61.89 g. sample taken for ana-
11.5	3170.5	.46	93.0	.131		lyses.
12.5	3159.0	14.91	91.0			
13.5	3164.5	1.67	93.0	.130		
14.5	3155.5	15.13	93.0	.127	.127, .125	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:52.5. Newly harvested corn dried to initial moisture content.

Table 15. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in an open container with silica gel in 3 cylinders and 3 sacks (15-3S-O) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3498.5	0	88.5	.158		Initial adsorbent wt.- 95.56 g.
.5	3476.0	26.46	93.5	.152		Desiccant dried every day at 130 C.
1.0	3459.0	21.25	93.5			
1.5	3458.0	3.61	93.0	.148		
2.0	3443.0	19.49	93.0			
2.5	3440.0	5.45	92.5	.143		
3.0	3425.5	18.75	93.0	.140	.130	65.84 g. sample taken for analyses.
3.5	3358.0	4.73	93.5	.139		
4.5	3341.5	22.37	93.5	.135		
5.5	3330.5	23.03	93.5	.132	.122	59.39 g. sample taken for analyses.
6.5	3256.5	23.63	94.5	.128		
7.5	3242.5	22.25	95.0	.124	.118	62.55 g. sample taken, desiccant dried every 2 days after this day.
8.5	3168.0	21.22	88.0			
9.5	3169.5	2.99	93.0	.121		
10.5	3156.5	22.44	92.0	.119	.115	62.72 g. sample taken for analyses.
11.5	3099.5	2.09	93.0	.120		
12.5	3089.0	20.21	93.0			
13.5	3092.0	3.26	92.5	.118		
14.5	3081.0	19.75	93.0	.114	.114, .115	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:35.5. Newly harvested corn dried to initial moisture content.

Table 16. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in a closed container with silica gel in 2 cylinders and 3 sacks (15-2S-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3451.0	0	87.5	.157		Initial adsorbent wt.- 71.95 g.
.5	3431.5	19.02	93.5	.152		Desiccant dried every day at 130 C.
1.0	3419.0	13.31	92.5			
1.5	3416.5	2.29	93.0	.149		
2.0	3403.5	11.98	92.5			
2.5	3399.5	4.09	93.0	.144		
3.0	3388.0	12.03	93.0	.141	.134	60.32 g. sample taken for analyses.
3.5	3325.0	3.33	93.0	.141		
4.5	3312.0	13.96	93.0	.137		
5.5	3297.5	13.91	93.0	.134	.115	58.15 g. sample taken for analyses.
6.5	3225.5	15.37	94.0	.130		
7.5	3212.0	14.22	93.0	.126	.109	62.63 g sample taken, desiccant dried every 2 days after this day.
8.5	3137.5	12.70	89.0			
9.5	3135.0	2.35	92.5	.122		
10.5	3122.5	13.41	92.5	.119	.103	61.94 g. sample taken for analyses.
11.5	3058.5	2.07	93.5	.118		
12.5	3047.5	11.37	93.0			
13.5	3045.0	2.96	92.5	.114		
14.5	3035.5	10.65	93.0	.111	.114, .113	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:48. Newly harvested corn dried to initial moisture content.

Table 17. Grain weight, temperature, and moisture changes during storage period for 15 percent M.C. corn stored in a closed container with silica gel in 3 cylinders and 3 sacks (15-3S-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3393.0	0	85.5	.156		Initial adsorbent wt.- 93.82 g.
.5	3367.0	25.39	93.5	.150		Desiccant dried every day at 130 C.
1.0	3349.5	17.50	93.0			
1.5	3346.0	3.34	93.0	.144		
2.0	3331.5	14.62	93.0			
2.5	3327.0	4.77	92.5	.139		
3.0	3312.0	15.56	92.5	.135	.123	60.22 g. sample taken for analyses.
3.5	3247.5	4.32	93.0	.134		
4.5	3230.5	17.59	93.5	.129		
5.5	3214.0	17.10	94.0	.125	.109	61.13 g. sample taken for ana-
6.5	3136.0	18.53	94.0	.120		
7.5	3119.5	17.16	93.5	.116	.103	65.62 g. sample taken, desiccant dried every 2 days after this day.
8.5	3040.0	14.69	88.5			
9.5	3037.0	2.85	93.0	.111		
10.5	3023.0	15.07	92.0	.107	.093	63.11 g. sample taken for analyses.
11.5	2957.0	2.60	92.5	.106		
12.5	2946.0	12.23	92.0			
13.5	2943.0	3.56	91.5	.101		
14.5	2932.5	11.33	92.5	.098	.098, .099	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:36. Newly harvested corn dried to initial moisture content.

Table 18. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in an open container with silica gel in 3 cylinders and 3 sacks (20-3S-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3503.5	0	87.0	.196		Initial adsorbent wt.- 98.52 g.
.5	3475.0	28.62	95.0	.189		Dropped sack, lost some silica gel, desiccant dried every day at 130 C.
1.0	3451.5	26.46	95.0			
1.5	3449.5	1.72	94.5	.183		
2.0	3426.5	23.48	93.5			
2.5	3424.5	4.11	94.5	.178		
3.0	3403.0	23.35	94.0	.172	.145	62.43 g. taken for analyses.
3.5	3337.5	3.63	95.0	.172		
4.5	3316.5	25.19	95.0	.166		
5.5	3296.0	25.46	96.0	.161	.139	59.71 g. taken for analyses.
6.5	3215.0	26.04	95.5	.159		
7.5	3193.0	25.07	94.0	.153	.128	61.75 g. taken for analyses, desiccant dried every two days after this day.
8.5	3113.5	24.34	89.0	.148		
9.5	3116.0	2.72	93.5			
10.5	3104.5	25.29	93.0	.145	.130	61.91 g. taken for analyses.
11.5	3045.0	.54	93.5	.146		
12.5	3028.5	23.59	93.0			
13.5	3030.0	1.71	92.0	.142		
14.5	3014.5	21.47	93.0	.138	.134, .132	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:35.5. Newly harvested corn dried to initial moisture content.

Table 19. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in an open container with silica gel in 4 cylinders and 3 sacks (20-4S-0) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3451.0	0	87.0	.190		Initial adsorbent wt.- 115.16 g.
.5	3421.0	33.93	96.0	.183		Desiccant dried every day at 130 C.
1.0	3390.5	32.09	95.0			
1.5	3388.5	2.18	94.5	.175		
2.0	3363.5	29.38	93.5			
2.5	3360.5	4.29	95.0	.168		
3.0	3338.5	29.31	95.0	.163	.153	60.64 g. sample taken for analyses.
3.5	3275.0	3.30	95.0	.162		
4.5	3249.5	31.14	94.5	.155		
5.5	3225.5	32.40	96.0	.149	.146	59.58 g. sample taken for analyses.
6.5	3140.5	31.36	97.5	.142		
7.5	3115.0	29.86	94.5	.135	.123	62.94 g. sample taken, desiccant dried every 2 days after the day.
8.5	3033.0	29.28	87.5	.130		
9.5	3033.5	2.69	93.5			
10.5	3013.5	28.95	92.0	.124	.115	64.03 g. sample taken for analyses.
11.5	2953.0	2.28	93.0	.125		
12.5	2937.0	27.51	93.5			
13.5	2943.0	3.56	93.0	.122		
14.5	2927.5	26.89	93.0	.118	.120, .117	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:30. Newly harvested corn dried to initial moisture content.

Table 20. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in a closed container with silica gel in 3 cylinders and 3 sacks (20-3S-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Content
0	3473.0	0	86.0	.193		Initial adsorbent wt.- 91.94 g.
.5	3444.5	26.46	95.5	.186		Desiccant dried every day at 130 C.
1.0	3420.5	24.29	95.0			
1.5	3418.0	1.63	93.5	.180		
2.0	3396.5	21.23	94.5			
2.5	3393.0	3.67	94.5	.174		
3.0	3371.5	20.62	94.0	.168	.149	60.38 g. sample taken for analyses.
3.5	3308.0	3.79	94.5	.167		
4.5	3286.0	22.05	95.0	.162		
5.5	3264.0	22.10	95.0	.156	.132	58.66 g. sample taken for analyses.
6.5	3183.5	22.87	96.5	.150		
7.5	3162.0	21.53	95.0	.145	.128	61.03 g. sample taken, desiccant dried every 2 days after this day.
8.5	3082.0	19.85	89.0	.139		
9.5	3078.5	3.08	94.0			
10.5	3059.5	19.31	93.0	.133	.109	61.46 g. sample taken for analyses.
11.5	2996.5	2.32	93.5	.133		
12.5	2979.5	17.17	93.0			
13.5	2976.0	3.17	92.0	.127		
14.5	2962.0	15.50	93.0	.123	.129, .125	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:38. Newly harvested corn dried to initial moisture content.

Table 21. Grain weight, temperature, and moisture changes during storage period for 20 percent M.C. corn stored in a closed container with silica gel in 4 cylinders and 3 sacks (20-4S-C) at 95 F and 90-100 percent R.H.[1]

Days in storage	Weight of grain (grams)	Increase in weight of adsorbent (grams)	Temperature (F)	Moisture content by weight	Moisture content by oven	Remarks
0	3410.5	0	85.0	.193		Initial adsorbent wt.- 118.06 g.
.5	3375.0	34.10	94.5	.184		Desiccant dried every day at
1.0	3344.5	29.97	95.0			130 C.
1.5	3340.5	3.59	93.0	.176		
2.0	3314.5	25.72	93.5			
2.5	3308.0	6.42	94.0	.168		
3.0	3285.5	23.30	93.5	.162	.140	61.24 g. sample taken for ana-
3.5	3218.0	5.47	93.5	.160		lyses.
4.5	3192.0	26.43	94.0	.153		
5.5	3167.0	26.37	95.5	.147	.125	60.24 g. sample taken for ana-
6.5	3081.0	26.54	95.5	.139		lyses.
7.5	3056.0	24.04	94.0	.132	.110	63.84 g. sample taken, desic-
8.5	2972.5	21.84	86.5	.128		cant dried every 2 days after
9.5	2968.5	4.23	94.0			this day.
10.5	2946.5	21.62	92.0	.118	.102	63.27 g. sample taken for ana-
11.5	2881.0	3.41	93.0	.117		lyses.
12.5	2863.5	17.88	92.0			
13.5	2858.5	4.62	91.5	.110		
14.5	2844.0	15.42	92.5	.106	.105, .107	Sample taken. No mold visible.

[1]Initial silica gel to corn ratio of 1:29. Newly harvested corn dried to initial moisture content.

Table 22. Percentages of kernels invaded by indicated storage fungi at various days in storage for the 12 percent moisture content samples.[1]

Sample	Days	Rhiz.	Mucor	Nigro.	Pen.	A. Flav.	% M.C.	% Germ.[2]
12-OS-O	5	10	10	0	6	0	12.3	
	7	18	6	4	4	0	12.5	
	10	12	4	2	4	0	12.7	
	14	6	8	0	6	0	12.2	96
12-OS-C	5	20	12	2	4	0	10.8	
	7	20	8	0	2	0	10.6	
	10	16	22	0	6	2	10.6	
	14	14	8	0	8	0	11.0	94
12 - Initial	0	10	4	2	4	0	11.6	97

[1]For mold test: 50 surface disinfected kernels per sample; plated on malt agar with 4% NaCl and 200 p.p.m. ergotol.

[2]200 kernels for germination samples.

Table 23. Percentages of kernels invaded by indicated storage fungi at various days in storage for the 15 percent moisture content samples.[1]

Sample	Days	Rhiz.	Mucor	Nigro.	Pen.	A. Flav.	% M.C.	% Germ.[2]
15-2S-0	3	12	6	2	10	0	14.0	
	5	10	4	0	12	0	13.0	
	7	18	0	0	2	0	12.5	
	10	6	6	2	0	0	12.9	
	14	28	8	0	10	2	12.6	94
15-2S-C	3	22	0	2	0	0	13.4	
	5	12	12	2	8	0	11.5	
	7	18	0	0	2	2	10.9	
	10	18	8	0	4	0	10.3	93
	14	18	8	2	4	0	11.3	
15-3S-0	3	26	6	2	4	0	13.0	
	5	20	6	0	6	0	12.2	
	7	12	4	0	8	4	11.8	
	10	18	6	0	4	0	11.5	
	14	16	10	0	14	0	11.4	91
15-3S-C	3	16	10	2	0	0	12.3	
	5	18	6	2	2	0	10.9	
	7	18	6	4	2	0	10.3	
	10	16	10	2	4	2	9.3	
	14	14	6	0	8	2	9.8	95
15 - Initial	—	—	—	—	—	—	—	94

[1]For mold tests: 50 surface disinfected kernels per sample; plated on malt agar with 4% NaCl and 200 p.p.m. ergotol.
[2]200 kernels for germination samples.
[3]No initial mold count data for the 15% samples.

Table 24. Percentages of kernels invaded by indicated storage fungi at various days in storage for the 20 percent moisture content samples.[1]

Sample	Days	Rhiz.	Mucor	Nigro.	Pen.	A. Gl.	A. Flav.	% M.C.	% Germ.[2]
20-3S-0	3	18	0	6	4	0	2	14.5	
	5	4	4	2	0	4	6	13.9	
	7	16	0	4	6	6	20	12.8	
	10	4	4	4	14	2	4	13.0	
	14	13	4	3	1	11	10	13.3	87
20-3S-C	3	2	2	0	0	0	2	14.9	
	5	6	6	4	4	0	6	13.2	
	7	10	4	2	6	2	6	12.8	
	10	6	4	4	6	0	4	10.9	
	14	13	4	1	2	7	11	12.7	89
20-4S-0	3	12	4	2	2	0	2	15.3	
	5	14	2	2	4	0	2	14.6	
	7	6	2	2	10	6	4	12.3	
	10	14	12	0	6	2	8	11.5	
	14	22	4	0	4	8	17	11.8	95
20-4S-C	3	16	6	6	2	0	0	14.0	
	5	16	4	0	4	0	2	12.5	
	7	16	4	0	6	2	10	11.0	
	10	18	6	0	2	0	8	10.2	
	14	12	1	2	5	2	0	10.6	88
20 Initial	0	12	12	0	4	0	0		93

[1]For mold tests: 50 surface disinfected kernels per sample; plated on malt agar with 4% NaCl and 20 p.p.m. ergotol; exception: 100 kernels plated for the 14 day mold count.
[2]200 kernels for germination samples.

APPLICATION OF DRYING AGENTS FOR SMALL SCALE ON-FARM DRYING AND STORAGE IN HUMID REGIONS OF DEVELOPING COUNTRIES

by

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The broad objective of this study was to develop a simple and inexpensive grain storage unit or method which can effectively be used at farm and local levels in humid areas of developing countries.. The approach taken was the possible uses of adsorbents to dry humid air surrounding the grain and to remove moisture from the grain. The grain used for the first series of tests was yellow corn at 12% moisture content purchased from a local elevator and for the last series of tests, newly harvested yellow corn at about 24% moisture content was used. Desiccants tested were lime, drierite, calcium chloride, salt and silica gel.

Small metal cans holding about 10 lbs. of corn were used as storage containers. For positioning and placing the desiccant, small screen cylinders, approximately 5/8 inch in diameter were constructed and placed in a container. The containers with no cylinder (only small sacks of desiccant on the top layer of grain), one, two, three, or four cylinders which were uniformly positioned in them were used to find proper grain to desiccant quantity ratios for preserving corn at 12, 15, and 20% initial moisture contents under humid environmental conditions. Also tested were the conditions of containers (lid closed, lid opened and holes at the side of container).

Proper frequency and temperature of desiccant regeneration needed for grain drying and storage were tested. Corn samples with various combinations of experimental factors were tested for storage performance at 90-95 F and 80-90% R.H. and 90-95 F and 90-100% R.H. in climate chambers. The changes in desiccant weight, grain weight, grain temperature, and grain quality (mold and germination) were periodically recorded.

The results showed that of the various drying agents tested, silica gel was the only one that may be effectively used for drying and storing corn in humid areas. The rate of drying of corn was affected by the grain to adsorbent ratio (the lower the ratio, the higher the rate), the frequency and temperature of silica gel regeneration, and also the condition of the container (the rate was faster for a container with the lid closed). Analysis showed that the rate of drying followed the form of this equation.

$$\frac{M - M_E}{M_o - M_E} = Ae^{-Kt}$$

The rate of water adsorption by silica gel was very high at an initial stage of storage and then decreased sharply. In general, about 70% of adsorptive capacity was used up within 24 hours after placing it into a container. Silica gel should be regenerated at approximately 130 C for 45 minutes.

The grain to adsorbent ratios needed to preserve the grain quality for 12, 15, and 20% initial moisture corn were 140:1 (only sacks on the top of grain layer), 50:1, and 35:1, respectively. Frequencies of silica gel regeneration needed were once every week for 12% moisture corn, once every day for a week and thereafter, every other day for another week for 15 and 20% initial moisture corn. Tests under these conditions showed no change in grain quality (visible mold and germination).

The cost analysis on the method developed, based on a one-ton storage unit, showed that the drying and storage cost is about \$2.68/ton/year or 7¢/bu./year (drying 20% to 12% moisture). If the method developed will prove to be workable for a larger unit, it would have many advantages over other conventional and non-conventional methods for grain drying and storage.