HIGH TEMPERATURE AND HIGH HUMIDITY GRAIN STORAGE

by

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INTRODUCTION

The tropical belt is the area which lies between the Tropic of Cancer and the Tropic of Capricorn and contains above one quarter of the land surface of the earth and more than one third of the world's population (1). Seven types of climate are distinguishable, each of which has its impact on the pattern of food supply and consumption in the areas and particularly on grain drying and storage problems after harvest. These climates may be defined as equatorial, tropical, desert, humid tropical, mediterranean, temperate and highland, which have characteristic natural and cultivated vegetation potentials.

Perishable and semi-perishable foods spoil because of chemical and physical changes brought about through the activity of one or more of the following groups of spoilage agents: molds, yeasts, bacteria.
Under proper conditions of humidity, temperature and oxygen supply the various members of these groups attack certain compounds in food material and can convert them into toxic compounds which render the food unfit for human consumption.

Grain is stored at common or normal temperatures or is refrigerated or cooled to preserve it. Moisture content or temperature slows the activity of all spoilage agents. In humid areas it is very common to find regions with more than 75 percent relative humidity. Temperature varies with altitude; at 1,800 meters (mt), the variation may be 17 degrees centigrade. Rigid classification of an area into one of these main climate regions is not always possible. Coastal low, for example, may have the main characteristic of hot dry areas (38 to 44°C) but high relative humidity.

This study is projected for the areas where the ambient relative humidity never falls below 70 percent. Relative humidity in these studies was lowered by raising the temperature of the air (for our case the temperature was 43°C, with the humidity reduced to 60 percent). At this temperature most of the species of insects are inhibited. According to these general comments we are going to determine the "commercial condition" of grain to predict its future storage behavior. Whereas mold count and viability tests are good indexes of incipient deterioration, test weight, cracking and breakage (handling), milling-baking, fat acidity and visual aspects indicate physical indexes of deterioration present in the grain. Corn, wheat, rice, sorghum, pinto beans and soy beans were used for the study. These grains were stored in sacks and bins. The bins were aerated during the experiment. For one lot A, corn was rewet and dried by natural and artificial methods.

The temperature of 43°C and relative humidity of 60% were selected because these conditions correspond to the same absolute humidity as 35°C and 90% relative humidity - a typical tropical condition. If dry grain, say 12% moisture, is stored at 35°C and 90% relative humidity it picks up moisture from the atmosphere and the moisture increases to the point where many molds grow. It was hoped that aerating with heated air at the lower humidity would keep the grain dry and prevent mold growth.

REVIEW OF LITERATURE

A. Diffusion of Moisture through the grain.

The physical properties and the storage of grain in bags or bulk are influenced widely by moisture content (MC), relative humidity (RH), equilibrium relative humidity (ERH), and velocity of the air. Babbit (23) and Van Arsdel (46) have proved that the vapor pressure is the main driving force for the moisture movement during a drying process. The difference between vapor pressure inside the kernel and the surrounding air produces the migration of water or water vapor from one point to another. The conductance variable is called permeability when the potential is vapor pressure, similar to the coefficient of heat transfer in conduction. Wang (21), in his theory of drying, demonstrated that diffusion of water vapor in the grain depends on whether the vapor pressure in the grain is greater or less than that in the surrounding air. When evaporation takes place, heat will be needed as latent heat. Various thermodynamic models have been discussed in detail, one of them by Chung and Pfost (7).

The effect of change of temperature on the equilibrium relative humidity is generally small, according to Ayerst (8).

Pixton and Warburton (9) found that for wheat, if the moisture content remained constant in the range of 10 to 20 percent, the equilibrium relative humidity increased or decreased approximately 3 percent for every 10^{o}C rise or fall in temperature.

Moisture is moved from one location to another by air convection currents or by vapor pressure differences. The temperature of the grain at the center of the sack or bin may rise due to the presence of insects. Hall (10) has shown that when large temperature differences exist, the heat flow between atmosphere and grain is responsible for differential warming or cooling of the grain. As the air is cooled, its relative humidity rises and may reach the saturation point when excess water is deposited on the surface of the cooler grain (24).

In warehouses Halliday (18) found that a period of high temperatures and low ambient relative humidities was reflected in lower moisture content on both the surface and in the bulk of stacks of bagged groundnuts.

B. Mold

After the seeds are harvested and stored they are subject to invasion and damage by a group of fungi designated as "storage fungi" (5). Members of the genera Aspergillus and Penicillum predominate in grain where the moisture content is in equilibrium with relative humidities of 65 to 85 percent (22). The percentage of relative humidity required appears to be lower at optimum than at suboptimum temperatures for growth on materials (43). Only a few molds grow at a moisture contents equivalent to a relative humidity of 65 percent; this has been suggested as a borderline for 2 to 3 years storage of grain and grain products held at 15 to 21°C.

The effect of relative humidity on spore germination has been studied by several authors. Block et al.(44) found that germination was very high at 90 to 95 percent relative humidity but decreased appreciably at lower temperatures and becomes restrictive at 75 percent relative humidity. Most of the twenty-one fungi he tested germinated to some extent at 80 percent relative humidity.

Scott (48) found that although micro-organisms can grow from close to 100 percent relative humidity down to values approaching 60 percent, most species are limited to a much smaller range. As a class, bacteria may grow at relative humidity as low as about 75 percent, whereas some yeasts and molds grow very slowly at 62 percent. Milner and Geddes (28) found that relative humidity rather than actual moisture content of seeds determines their susceptibility to molding.

Most fungi grow within the range of 4 to 49°C. There are many that grow at temperatures below this range (as low as -8°C) and some thermophiles grow in the range of 50 to 76°C (22). However, most common storage molds have their optimum growth in the range of 20 to 35°C. Togashi (50) lists several hundred fungi and bacteria important as plant pathogens, the majority of which grow in the 4 to 49°C range. Block et al. (44) found that there was almost complete germination of the spores of twenty-one fungi at 27 to 38°C in 32 days; at lower temperatures there was lower germination even at 95 percent relative humidity. Bottomley et al. (16) found that the development of naturally-occuring microflora of corn is dependent not only on the availability of moisture, but also on temperature and on atmospheric conditions. Thus, corn in equilibrium with relative humidity of 80 percent and over, supported predominately *Penicillium* at 25°C, *A. flavus* at 30°C and *A. glaucus* at 35°C. Temperatures of 40 to 45°C limited mold development, but at 45°C *Mucor* was predominant.

C. Respiration

Respiration of corn is only slight at moisture contents below 14.7 percent but marked acceleration occurs at higher moisture (35). At the same temperature and corresponding moistures Milner et al. (30) found that corn respired more rapidly than wheat at all moisture levels. In practice it is difficult to differentiate between respiration of the grain and respiration of associated microorganisms.

The effect of aeration, temperature, and time on the respiration of soybeans containing excessive moisture was studied by Milner and Geddes (27). They found that under nitrogen, the respiratory activity in soy beans was extremely low and remained constant for any given temperature over the period time. On the other hand, in the presence of air, mold growth appeared and increased with aeration at all temperatures below 45°C. This was accompanied by an increase in oil acidity. Aeration rate influenced respiratory activity when insufficient to maintain concentrations of carbon dioxide in the interseed air below approximately 12 to 14 percent. Respiration under nitrogen remained constant with time at a rate of approximately 3 percent of that under optimum aeration.

Bottomley et al. (16) studied the influence of various temperatures, humidities, and oxygen concentration on mold growth and biochemical changes in stored yellow corn. He and his co-worker found that the mold count increased with increasing relative humidity and decreased as the oxygen content of the atmosphere was lowered and as the temperature was raised from 25 to 30°C. At 40°C A. flavus flourished at both low and high humidities, but A. glaucus was dominant at 80 to 90 percent relative humidity. At 45°C and 75 to 85 percent relative humidity high counts of mold were found. With respect to loss of dry matter in stored corn they found that the variation in atmospheric composition caused smaller changes in mean loss than did variation in temperature. The maximum loss occurred when the corn was stored under air and the minimum under anaerobic conditions. They also found that below 90 percent relative humidity the effect of increasing the temperature from 25 to 45°C was not marked. Above this relative humidity and particularly at 95 and 100 percent, the effect of higher temperature was reflected by greater losses of dry matter. Similarly, below a relative humidity of 90 percent the effect of variations in atmosphere or humidity upon dry matter loss was not pronounced. The maximum loss occurred in the sample stored under air with a relative humidity of 100 percent at a temperature of 40°C. They concluded that the loss in dry matter in corn is a result of seed respiration and/or metabolism and respiration of the molds. Teter and Roane (32) concluded that climatic conditions (25 to 37°C and 80 percent relative humidity) favor mold development on corn during the drying period. According to them, air flow delivery of between 8.98×10^{-3} to 17.95×10^{-3} cubic meter of air per minute (CMTPM) per cubic meter of grain (CMT) (9 to 18 CFM/bushel), was optimum for production of No. 2 corn as indicated by visible mold development. Navarro (31) concluded that aeration is effective in cooling grain and in maintaining low temperature under atmospheric conditions of 0 to 32°C with the relative humidity between 80 to 100 percent. The grain was cooled to 10 to 14°C. This change of micro-climate in the grain bulk results in limiting the development of the common stored products insect species also. According to him, aeration of grain in storage over long periods in subtropical climates with a cool season is a practical proposition.

Moisture content is recognized as the most critical of all the factors influencing the respiration, heating and deterioration of seeds. Hummel, Cuedent and Christensen (19) found that respiration is insignificant if the moisture content of the seeds is sufficiently low. In wheat, respiration is very low at a moisture content of 12 percent even if the temperature is as high as 30°C; respiration is several hundred times more intense with a moisture content of 30 percent.

D. Germination

Amen (1) defined dormancy as a physiological adaption which delays germination until favorable environmental conditions are likely to occur. Consequently dormant seeds do not germinate under conditions which may be favorable for normal growth. The factors reside in the outer layer of the grain and they can be broken when those layers are removed or damaged. Dormancy depends on the temperature during the dough stage. This stage is in the intermediate phase of ripening which follows the milk stage and ends with harvest ripeness (1).

Half viability, according to Roberts (38), is defined as the time taken from harvest until germination has dropped to 50 percent. It is conditioned by temperature and humidity.

In the tropics it is difficult to maintain valuable breeding stocks of viable seed. Robertson (39) showed that the length of life of both fungicide treated and untreated seed in storage increases as the humidity decreases over the range studied. In his experiment he found that serious problems were presented by all grains at 100 percent relative humidity within a month and only a slight loss in viability was found in the same samples at the end of 1,032 days of storage at 57.6 percent relative humidity.

The Institute for Storage and Processing of Agricultural Products, Wageningen, in cooperation with the National Institute for Brewing Barley, Malt and Beer T.N.O., Rotterdam, Netherlands, found that if dry matter losses as high as 1 percent or more have occurred during storage, a considerable decrease in viability has also taken place and mold growth has started (26).

The influence of fungi on storage, on seed viability and seedling vigor of soybeans has been studied by Tervet (20). He found that at different moisture contents (6.51 to 21.2 percent) and temperatures (29.4 to 77°C), Alternaria spp. were most frequently found with Fusarium spp. and bacteria next in soybeans. Also the percentage of seeds with Aspergillus spp. increased with temperature up to about 45°C. The maximum number of infected seeds was found at about 45°C while at 60°C no seeds were infected. A. flavus, A. ochraceus, and A. glaucus predominated in infected seeds. Spores of A. flavus dusted on soybean seeds resulted in the retarded development of the seedling, while spores of A. niger, A. ochraceus or of any other fungus obtained from soybean seeds caused no abnormal seedling development. Roberts (38) showed that moisture is an important consideration as far as seed viability is concerned. Loss of viability and fungal activity has only been shown at the higher humidities; in fact the evidence indicates that storage micro-organisms are inactive at relative humidities below about 65 percent (42).

Drying temperature is a factor in viability of the seeds. Kiesselbach (45) found that if a suitable procedure is followed in artificial drying, no injury results to viability or field performance of the seed. Maximum temperature for corn is 44°C at normal harvest moisture. According to Kiesselbach the permissible moisture content for safe processing and storage is approximately 5 to 14 percent. He found that ear corn dried for 35 days at 41°C contained 4.3 percent moisture and its germination was 98 percent. Brown (12) showed that temperature in storage at 41°C is not important for the loss of viability. After 6 months of storage at 6 percent moisture content he found that germination in sorghum was 97 percent at 20°C*, 98 percent at 30°C* and 80 percent

*Germination temperature.

after sorghum was dried at 45°C for 19 days to a moisture content of 6.5 percent. In contrast, Carter (13) found that wheat stored in sealed containers at 40°C, and 16.2 percent moisture content had no germination after 59 days.

E. Stress Cracks and Breakage

The state of maturity at which the grain is threshed, storage conditions and methods, temperature, moisture content, variety and method of stressing are factors which influence visible mechanical damage such as cracked or broken kernels. Gordon et al. (15) found that cracks, radial and transverse to the crease, occur in hard vitrous endosperm during water movement through the kernels at moisture levels in the range employed in commercial operations. According to that study, natural weathering (wetting and drying) or grain tempering prior to milling creates an additional internal endosperm stress which, when added to the maturing stress, causes the stress within the endosperm to exceed the breaking point, thus producing cracks. Tarle and Ceaglske (11) in a study of factors causing checking in macaroni, presented evidence as to the mechanics due to stress arising from unequal moisture gradients produced by addition of moisture. Physical properties of weathered wheat in relation to internal fissuring detected radiographically were studied by Milner and Shellenberger (29). They found that the reduction in density caused by natural weathering is due to the formation of internal fissures. According to them, rapid drying of immature grain at high moisture content does not produce fissuring. Katz et al. (41) found that hardness of wheat kernels has no significant change up to a moisture content of 13 percent, but there are some differences after 15 percent moisture content. Bilansky (49) found that the resistence of grains to impact damage increased as the moisture level increased. Under a gradually applied load, the high-moisture grain required the most work to produce damage; however, the grains became permanently deformed at a lower load than the drier grains. He concluded that the size, moisture content, type of load and position of the grain all influence its damage resistence. Corn and soybeans in that experiment required a greater amount of work to cause damage than the smaller grains.

Thompson and Foster (36) found that corn dried with heated air (60 to 116°C) was two or three times more susceptible to breakage than the same corn dried with unheated air. They also found that corn harvested at initial moisture near 30 percent broke easier than that harvested at 20 percent moisture. Most of the stress cracks were formed while corn was drying in the moisture range from 19 to 14 percent. Rapid cooling of dried corn added to the drying stress increased the number of stress cracks. With respect to the moisture content, they concluded that when it is reduced to below 13 percent, breakage increased rapidly and when the temperature is reduced from 29 to 14.5°C the amount of breakage doubled.

Pneumatic handling of sorghum grain was studied by Pearson et al. (33). In that study the minimum velocity ranged from approximately 914.35 to 1432.5 meters per minute. These velocities varied according to the arrangement of the system. After storage, there was considerable decrease in germination.

F. Insects

Insects are mostly of subtropical origin and have not developed resistence to low temperatures. Rice weevils are dormant at a temperature of 7°C (40). Most writers agree that few eggs are laid at temperatures below 15°C. A grain temperature of 21°C is considered ideal for insect growth. With a few exceptions, temperatures above 35°C are unfavorable for reproduction, oviposition ceases, and adults are short lived (9). Gay and Ratcliffe (14) reported the loss of reproduction of the lesser grain borer at 37°C; for prolonged periods at higher temperatures, death will occur.

Rice and granary weevils are unable to breed in grain with moisture content below 9 percent, and the adults soon die in dry grains (8). Temperature directly influences a weevil's ability to reproduce in grain. Even when provided with favorable 14 percent moisture content wheat, few rice and granary weevil progeny were produced at 15°C, but then greatly increased up to 26°C and fell greatly at 32°C.

Heating of grain can be caused by insects. According to Christensen (6) there are two types of heating. The heating caused by insects at a moisture content of approximately 15 percent or less results in temperature increases up to 42°C and the second type of grain heating is caused by a microorganism which occurs in grain with a moisture content approximately 15 percent or more and produces temperatures as high as 62°C. According to this general information, 3 types of insects, each one with a grade of resistence to survive at high temperatures (43°C) were selected for the experiments.

G. Fat Acidity, Grading and Milling-Baking Tests

A primary objective in food grain storage is to keep the original nutritional and palatability qualities of the product. Indices of deterioration of grain in storage can be measured by tests commonly used in grain grading; they are moisture, odor, damaged kernels, mold and insect damage. Abnormal odors are usually associated with grain that is heating or that is badly deteriorated; they are usually caused by the growth of certain molds and appear in the early stages of deterioration. Many investigators present correlation coefficients between fat acidity and percentage of damaged kernel or fat acidity and germination; generally those values are +.90 and -.85 respectively (51). Also, the increase in fat acidity is related to baking performance when the flour was stored at 38°C. In damaged flour, mixing times of doughs are consistently and substantially longer than those of doughs from sound flour. Bread baked from damaged flour is substantially lower in loaf volume and poorer in crum grain than bread baked from sound flour.

MATERIALS AND METHODS

A. Source of Grain

Five different grains were used. Wheat, sorghum, soybeans and corn were supplied by the Kansas Agricultural Experiment Station and USDA Grain Marketing Research Center. Long and medium varieties of rice were supplied from Louisiana State University. Pinto beans were mailed from Colorado State University. All grains except pinto beans are from 1975 crops. The following nomenclature was followed for identification of the grains:

Corn: Lot A (CH_1, CH_2, and CH_3), Lot B (1PI)

Beans: 2PB

Rough Rice: Long grain (3LA), Short grain (3VI)

Sorghum: Lot 1 (4AC), Lot 2 (4OR)

Soybeans: Lot 1 (5Co Ae), Lot 2 (5PO)

Wheat: Hard red winter; Lot 1 (6CE), and Lot 2 (6CL)

CH-1, CH-3 were dried from 22 and 12% moisture and 60°C (140°). CH-2 was dried with unheated air. See Appendix for details of coding of samples.

B. Preparation of Material for Storage

Grain was prepared for storage by:

1. Cleaning: Each grain was passed through the Carter Dockage Tester. Sieves and air flow were those specified by the official grain standards.

2. Wetting: This treatment was made for CH-1, CH-3 and CH-2. The initial and final moisture contents were 14% to 22% and 20% (wet

basis). The water was added over a six hour period.

3. Artificial Drying: Lots CH-1, CH-3 of corn were dried artificially. The drier used was an *Aeroglide type* cabinet. The feeder and temperature were controlled at 12.19 MTM (40 FPM), and 60°C (140°F). The maximum grain temperature was 58°C. The initial and final moisture content of the grains were 22% and 12.5% (wet basis).

4. Natural Drying: Lot CH-2 of corn was dried naturally out of doors. The initial and final moisture of that grain was 20% and 12.5% (wet basis). To dry, it was spread in thin layers on a screen. The weather condition during the eight days of the drying was: 50-60% RH, 7°C to 15°C and the velocity of the wind was 16 to 32 KMT per hour (10 to 20 miles per hour).

A representative sample of each of the seeds was stored at 8°C (47°F), to be used for determining the initial values.

Immediately prior to storage, the seeds were inoculated with common storage fungi. Cultures of Aspergillus repens and A. ruber (both members of the A. glaucus group) and of A. restrictus were grown to sterile, moist corn and wheat. The small grains (wheat, sorghum, rough rice) were inoculated by adding about 20 grams of the corn cultures of A. repens and A. ruber to each of the grains and mixing for 10 minutes in a mixer. The corn kernels were removed by sieving before the grains were dispensed into burlap bags or placed in the small bins. Soybeans, pinto beans and corn were inoculated with cultures of A. repens, A. ruber and A. restrictus grown on wheat. The wheat kernels were also removed before the beans and corn were stored.

C. The Storage Facilities

This experiment was performed in a high temperature room in the

Department of Grain Science and Industry of Kansas State University. Steam radiators are controlled by an electrical thermostat. The mean and range of temperature during the time of the experiment were 44°C (110°F) and 41 to 45°C (106 to 113°F). The relative humidity was maintained by a humidifier which was controlled by the humidistat. The mean and range of wet bulb temperature (TW) were 34°C (93°F) and 33 to 34°C (91 to 94°F). The mean and range of relative humidity were 55%, and 48 to 64% (wet basis). Three times per day, the readings of the dry bulb thermometer (TD) and wet bulb thermometer (TW) were checked. A sling psychrometer and wet-bulb, dry-bulb hygrometer were used. The accuracy of these thermometers was checked before and during the experiment.

The sizes of the steel bins used for aeration were .3048 diameter by .762 meters high. The capacity of the centrifugal fan used was .3751 cubic meters per minute (CMTM) (13.25 CFM) and the air flow was controlled for each of the bins by means of a valve. The air velocity was taken on the top of the bins by Hasting Air Meter Model B-22. Table 1 gives the values of velocities, column of grain, volume and amount of air supplied to the bins.

Table 1. Velocities and amount of air supplied to the bins.

GRAIN	AIR VELOCITY (MT/MI)	COLUMN OF GRAIN (MT)	VOLUME OF GRAIN (MT^3)	AIR SUPPLY (CMTM/CMT)
CORN (ICH-I)	15.24	.3048	.02223	.00133
PINTO BEANS (5 CO-Ae)	13.71	.3556	.02579	.00162
SORGHUM (4 OR-Ae)	137.15	.4506	.03223	.0133

D. Evaluation of Changes During Storage

1. Test weight: This test was made on each sample for initial and seven weeks' storage. The units are kilogram per hectoliter.

2. Moisture: Three methods were used. The first one was: the whole grain and beans were put in a forced-air oven at 100°C for 72 hours (first set). For the second method the time was the same but the oven was at 103°C (second set). For the last one, corn, rice and soybeans were put in the oven at 103°C for 72 hours; wheat, 130°C and 19 hours; sorghum, 120°C and 20 hours (third and fourth set).

3. Germination: These tests were made by Kansas State Board of Agriculture, Topeka, Kansas.

4. Visual inspection: This test was made by the State Grain Inspection Laboratory, Topeka, Kansas.

5. Fat Acidity, Milling-Baking: These tests were made by the Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas.

6. Breakage: Samples of each of the grains and soybeans were analyzed before and at the end of 10 weeks. The evaluation of this test (35) was made with a Stein Tester, Model CK-2, Serial No. 102 at room conditions. The following was the general method:

a. Representative samples were taken for each grain

b. The moisture content was determined

c. The weight of each sample was 100 $\pm$ 0.02 gms.

d. Samples were treated for 2 minutes in the breakage tester

e. The samples were placed, before and after the treatment, in a Gamet shaker. It was controlled by automatic counter set for 30 strokes. The screens used were the following:

wheat, 1.621 x 9.52 millimeters (mm) (0.064 x 3/8 in) slot. Soybeans, 3.96 x 19.05 mm. (10/64 x 3/4 in) slot. Grain sorghum, 1.98 mm (5/64 in) triangular. Corn, 4.76 mm. (12/64 in) round.

f. The grain remaining on top of the sieve was weighed and the loss in weight calculated as the percent breakage.

7. Stress Cracks: Corn samples were examined for stress cracks by candling each kernel individually. The light for candling was passed through a small, square, glass-covered opening in a box containing a 150 watt flood lamp. The position of each kernel was changed several times to see all stress cracks. The stress cracks were classified into single, multiple and checked or creased kernels (37). The weight of each sample was 50 grams. All foreign materials, broken, cracked or otherwise physically damaged kernels with a "chalky" endosperm were removed. The weight of each category was computed.

8. Fungal Invasion: Samples of each of the grains and beans were examined for initial invasion and for invasion after six and twelve weeks of storage. The seeds were surface sterilized by washing in absolute ethanol for 30 seconds and then in 2% sodium hypoclorite (common household bleach) solution for 1 minute followed by two rinses in sterile, distilled water.[1] Fifty seeds were placed on malt agar (Difco) containing 4% sodium chloride and 200 ppm. Tergitol (Union Carbide Corporation). The agar plates were incubated at 25°C for 6 to 8 days. The fungi growing from the seeds were identified using a binocular microscope with magnification

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[1]The first tests for mold did not include the alcohol wash, and showed almost complete internal infection. It was concluded that the procedure was not correct. The procedure was then modified by washing first in ethanol. Dry spores on the surface of the grain appear to be resistant to the normal hypochlorite washing.

of 10 to 100 times.

9. Insect resistance to temperature: The Department of Entomology, Kansas State University supplied culture jars of red flour beetles (Tribolium castaneum), lesser grain borers (Rhyzopertha dominica) and Kansas State rice weevil (Sitophilus oryzae), all 10 to 14 days old. These were placed in the high temperature storage room; after 1, 2, 4 and 6 days, one jar of each variety was taken and placed in a rearing room for 35 days at 25°C and 67% relative humidity. Then, the number of live insects were counted.

RESULTS AND DISCUSSION

The effects of storage conditions on moisture content, test weight and germination are shown in Table 2. The equilibrium temperature of the center of the sacks was reached by most of the grains in the first two weeks. Pinto beans (2PB) was the only grain that absorbed water from the surroundings. The two varieties of sorghum were stored with the highest initial moisture content.

Table 3, 4 and 5 summarize the experimental findings with respect to fungal invasion.

Initially, all cereals and beans were free of invasion by storage fungi except for the soybeans stored in the burlap bag (lot 2). Invasion in this lot was only 2% by *A. glaucus*. The small grains were 100% invaded by field fungi (*Aternaria*, *Cladosporium*, *Helminthosporium*, *Fusarium*); corn kernels in Lot 1 had low initial fungal invasion and lot 2 had higher numbers of *Fusarium*. The soybeans and pinto beans were essentially fungus-free. At the end of 3 months storage at 55% relative humidity and 43.81°C, several of the grains were apparently invaded by the inoculated storage fungi. *A. glaucus* counts ranging from 93% in aerated Lot 1 corn to 3 in aerated sorghum were recorded. None of the tests scored zero invasions.

The literature indicates that storage microorganisms are inactive at relative humidity below about 65% (22, 52, 44). Bottomley (16) found temperatures of 40 to 45°C limited development of *A. glaucus* and *A. flavus*. The storage conditions of this experiment were considered to be limiting

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Table 2. Effect of storage condition on moisture content, test weight and germination

GRAIN		MOISTURE CONTENT (Wet Basis)				TEST WEIGHT[1] (Kilograms/Hectoliters)			GERMINATION		
		WEEKS									
		0	7	10	12	0	7	Reduction %	0	7	12
CORN											
LOT A	1CH-1	12.49	10.27	10.15	10.71	73.31	72.62	.94	74	51	3.00
	1CH-2	12.37	10.04	9.92	10.07	74.06	73.77	.39	88	77	64.00
	1CH-3	12.35	10.08	9.91	10.20	74.40	73.94	.61	74	68	11.00
LOT B	1P1	11.14	9.86	9.95	10.31	75.54	75.33	.31	92	68	12.00
BEANS	2PB	10.27	10.67	10.51	11.00	76.50	75.92	.32	78	78	52.00
ROUGH RICE											
Long	3LA	10.51	9.77	9.38	9.54	59.42	58.91	.85	91	70	55.00
Short	3VI	10.75	9.61	9.67	9.77	58.90	57.89	1.63	91	75	41.00
SORGHUM											
LOT A	4OR-Ae	12.89	10.67	10.79	10.58	74.20	73.26	1.20	69	45	32.00
	4OR	12.89	10.88	10.96	11.18	74.20	72.86	1.80	69	42	15.00
LOT B	4AC	14.19	10.82	10.79	11.03	76.50	75.72	1.00	87	72	32.00
SOY BEANS											
LOT 1	5CO-Ae	9.00	7.93	7.70	7.92	73.15	72.68	.64	77	67	29.00
	5CO	8.60	8.47	8.23	8.46	73.51	73.23	.38	82	83	44.00
LOT 2	5PO	8.26	8.03	7.90	8.22	74.34	74.23	.14	87	79	35.00
WHEAT											
LOT 1	6CE	11.75	10.67	11.03	11.23	78.24	78.06	.23	92	46	15.00
LOT 2	6CL	10.99	9.95	10.50	10.74	79.33	79.08	.31	95	82	67.00

1/ Average of three readings.

2/ See Appendix for details of sample coding.

Table 3. Moisture content, germination and fungal invasion of corn stored at 55% RH and 43.81°C

GRAIN	Treatmet	Storage Method	Weeks	% M.C	% Germ.	% of kernels invaded by Aspergillus Glaucus	Fusarium	Penicillium	% Alternaria.
CORN LOT A	Natural Drying	B. bag (ICH-2)	0	12.37	88	0	22	4	2
			7	10.04	77				
			10	9.92					
			12	10.07	64	82	0	0	
	Artificial Drying	B. bag (ICH-3)	0	12.35	74	0	22	4	2
			7	10.08	68				
			10	9.91					
			12	10.20	11	66	0	0	0
		Aeration (ICH-1)	0			0	22	4	2
			7	10.27	51				
			10	10.15					
			12	10.71	3	93	0	0	0
LOT B	None	B. bag	0	11.14	92		78	0	24
			7	9.86	68				
			10	9.95					
			12	10.31	12	6	0	0	0

Table 4. Moisture content, germination and fungal invasion of sorghum grain, rough rice and wheat stored at 55% RH and 43.8°C

GRAIN	Storage Method	Weeks	% M.C	% Germ.	% of kernels invaded by A. glaucus	% Field fungi [1]
SORGHUM	B. bag (4 AC)	0	14.19	87	0	100
LOT I		7	10.82	72		
		10	10.79			
		12	11.03	32	6	0
LOT 2	B. bag (4OR)	0	12.89	60	0	100
		7	10.88	42		
		10	10.96			
		12	11.18	15	6	4
	Aeration (4OR-Ae)	0	12.89	69	0	100
		7	10.67	45		
		10	10.79			
		12	10.58	32	3	1
ROUGH RICE LONG	B. bag (3 LA)	0	10.51	91	0	100
		7	9.77	70		
		10	9.38			
		12	9.54		4	
SHORT		0	10.75	91	0	100
		7	9.61	75		
		10	9.67			
		12	9.77		34	
WHEAT	B. bag	0	11.75	92	0	92
LOT I	(6 CE)	7	10.67	46		
		10	11.03			
		12	11.23	15	13	0
LOT 2	B. bag (6 CL)	0	10.99	95	0	100
		7	9.95	82		
		10	10.50			
		12	10.74	67	5	0

[1] Includes species of Alternaria, Cladosporium, Fusarium, Helminthosporium

Table 5. Moisture content, germination and fungal invasion at 55% RH and 43.81°C

GRAIN	Storage Method	Weeks	% M. C	% Germ.	% of kernels invaded by A.GLAUCUS	% Field fungi [1]
SOY BEANS						
LOT 1	B. bag (5 CO)	0	8.60	82	0	2
		7	8.47	83		
		10	8.23	--		
		12	8.46	44	37	0
2	Aeration (5 CO)	0	9.00	77	0	10
		7	7.93	67		
		10	7.70	--		
		12	7.92	29	66	0
3	B. bag	0	8.62	87	2	4
		7	8.03	79		
		10	7.90	--		
		12	8.72	35	42	0
BEANS	B. bag	0	10.27	78	0	14
		7	10.67	78		
		10	10.51			
		12	11.00		58	0

[1] Includes species of Alternaria, Oladosporium, Fusarium, Helminthosporium.

to fungal growth, and the original invasion by field fungi was no longer detectible except in rough rice after 3 months. Wheat and sorghum were not invaded by A. glaucus to a significant level. The apparent invasion of A. glaucus in corn, sorghum and pinto beans cannot be explained in terms of present information on high temperature storage. Again, in view of the technical problem of washing inoculum from the seeds after high temperature storage, the actual numbers obtained after 12 weeks may not be important. However, it appears that corn, sorghum, pinto beans and rough rice may be invaded under these extreme conditions.

Germination at the end of the 7 weeks' storage was considerably reduced in aerated corn (1 CH-1), Lot B (1 PI) corn, both sorghums (4 OR-Ae 4 OR), wheat (6 CE), rice (long grain, 3 LA) and no differences in pinto beans (2 PB) and soybeans (5 CO). The higher moisture content appears to reduce germination significantly.

Tables 6 and 7 show the number of stress cracks in corn after wetting. The percentage of single stress cracks was more than multiple cracks. Thompson suggested that single stress cracks develop under conditions of less drying than those causing multiple cracks. The single stress crack was attributed to the room air.

Table 8 shows the effects of drying on stress cracks in corn; cracking increased considerably due to artificial drying.

Table 9 shows the effects of storage conditions on stress cracks in corn. Stress cracks increased in the 1CH lots but not in the 1 PI lot.

Table 10 shows the effect of drying on breakage in corn. There is no consistent difference.

Tables 11 and 12 show the effect of storage conditions and moisture changes on breakage in two varieties of corn and sorghum

Table 6. Number of stress cracks in corn after wetting

TREATMENT	%					
Wetting from 14 To 22 %	CORN (ICH-1)					
	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Sound kernels 71.16 %	13.60	17.41	4.00	5.50	7.20	5.93
	20.00		4.50		3.80	
	18.64		8.00		6.80	

TREAMENT	%					
Wetting from 13 To 20%	CORN (ICH-2)					
	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Sound kernels 79.45%	10.90	9.70	6.20	6.55	2.70	4.30
	8.80		9.90		6.80	
	9.40		3.50		3.40	

TREATMENT	%					
Wetting from 14 To 22%	CORN (ICH-3)					
	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Sound kernels 81.37%	10.44	9.13	1.64	4.39	5.60	5.12
	11.64		6.56		2.06	
	5.32		4.98		7.70	

Table 7. Breakage in corn in percent after wetting

AVERAGE %					
MOISTURE CONTENT (W.B)					
ICH-1		ICH-2		ICH-3	
22		20		22	
.46	.436	.46	.663	.56	.7066
.35		.73		.60	
.50		.80		.96	

Table 8. Effects of drying on number of stress cracks in corn

TREATMENT	%					
Drying Air	CORN (ICH-1)					
Temp; 60°C.	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Method: Batch	13.90		54.00		25.64	
Sound kernels	13.70	14.08	50.70	55.88	27.40	24.20
5.84 %	14.66		62.96		19.56	

TREATMENT	%					
Natural Drying	CORN (ICH-2)					
Temp. 4-10°C	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
	14.90		4.50		5.50	
Sound kernels	8.58	10.89	5.80	5.20	6.20	5.46
78.45%	9.20		5.30		4.68	

TREATMENT	%					
Drying Air	CORN (ICH-3)					
Temp: 60°C.	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Method: Batch	16.60		45.00		14.00	
Sound kernels	25.20	20.66	38.70	42.56	11.70	14.30
22.48%	20.20		44.00		17.20	

TREATMENT	%					
None	CORN (IPI)					
	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
	26.20		10.90		5.30	
Sound kernels	23.60	24.53	11.90	11.33	4.20	4.60
59.54%	23.80		11.20		4.30	

Table 9. Effects of storage time and/or drying condition on number of stress cracks in corn

TREATMENT	%					
Temp: 43.81 °C RH: 55 %	CORN (ICH-1)					
7 Weeks	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Aerated	10.4		50.4		37.2	
cmt/cmt: .00133	4.0	7.1	48.3	51.73	45.5	38.7
Sound Kernels 2.47%	6.9		56.5		33.4	

TREATMENT	%					
Temp: 43.81°C RH: 55 %	CORN (ICH-2)					
7 Weeks	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Unaerated	23.36		3.7		3.2	
Sound Kernels	20.7	23.15	3.5	3.56	4.68	4.29
69%	25.4		3.5		5.0	

TREATMENT	%					
Temp: 43.81 °C RH: 55%	CORN (ICH-3)					
7 Weeks	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Unaerated	18.6		53.2		18.6	
Sound Kernels	22.6	21.73	49.0	52.2	23.0	18.8
7.27%	24.0		54.4		14.8	

TREATMENT	%					
Temp: 43.81°C RH: 55%	CORN (IPI)					
7 Weeks	SINGLE	AVERAGE	MULTIPLE	AVERAGE	CHECKED	AVERAGE
Unaerated	21.7		11.7		7.6	
Sound Kernels	19.6	21.5	9.9	10.63	6.2	5.6
62.27%	23.2		10.3		3.0	

Table 10. Effect of drying on breakage in corn in percent

AVERAGE %					
MOISTURE CONTENT (W.B)					
I CH-1[1]		I CH-2[2]		I CH-3[1]	
12.49		12.37		12.35	
BREAKAGE		BREAKAGE		BREAKAGE	
8.97	8.80	3.35	3.08	3.40	3.59
8.23		3.30		3.70	
9.20		2.60		3.67	

1| Artificial drying

2| Natural drying

Table 11. Effect of storage conditions on breakage in two varieties of corn in percent

AVERAGE %							
MOISTURE CONTENT (W.B)							
ICH-1[1]				ICH-3			
12.49		10.15		12.35		9.91	
0 (Weeks)		10 (Weeks)		0 (Weeks)		10 (Weeks)	
8.97	8.8	19.21	19.89	3.40	3.59	10.50	9.43
8.23		20.79		3.70		10.35	
9.20		19.69		3.67		7.46	

[1] Aerated: .00133 CMTM/CMT

AVERAGE %							
MOISTURE CONTENT (W.B)							
ICH-2				IPI			
12.37		9.92		11.14		9.95	
0 (Weeks)		10 (Weeks)		0 (Weeks)		10 (Weeks)	
3.35	3.08	5.08	4.73	4.64	4.50	6.61	7.06
3.30		4.47		3.90		6.69	
2.60		4.65		4.97		7.90	

Table 12. Effect of storage conditions on breakage in two varieties of sorghum in percent

AVERAGE %							
MOISTURE CONTENT (W.B)							
4 OR				4 AC			
12.89		10.96		14.19		10.79	
0 (Weeks)		10 (Weeks)		0 (Weeks)		10 (Weeks)	
.74	.72	1.04	.89	1.03	.93	1.67	1.54
.66		.71		.88		1.44	
.76		.93		.90		1.52	

respectively.

Table 13 and 14 show the effects of storage time (little drying occurred) on breakage of soybeans and wheat respectively. Storage time had little effect.

In conclusion, the corn sample that was dried with unheated air had only single cracks in a few of the kernels, while that dried with heated air had multiple cracks, with many kernels exhibiting a checked or creased appearance. During the 10 weeks of storage, these were increased in single-multiple and checked stress in unaerated corn. In soybeans and small grains the percentage of increase was less than 1.65% considered normal for the conditions of the experiment.

At the end of the experiment each grain was observed with respect to possible attacks of insects, but there was no evidence. Table 15 shows insect survival after 1, 2, 4 and 6 days exposure to the given storage conditions, very few insects survived 6 days at 43°C.

Table 16 shows the effect of storage conditions on visual observation in grains and beans after 12 weeks' storages at 43.81°C and 55 percent relative humidity. Lot "A" of corn had an appearance typical of long term storage. The other grains kept the original appearance at the end of the experiment. Pinto beans darkened significantly.

Table 17 shows the flour characteristics of two varieties of wheat stored at 44°C and 55 percent relative humidity. Protein and ash content appeared unaffected in both samples. From Farinograph readings for the wheat sample 6CL there were significant changes in peak, arrival and departure time. The Amilograph showed more malt requirements in both flours at the end of the experiment.

A taste test of pinto beans was performed by a panel of seventeen

Table 13. Effect of storage conditions on breakage in two varieties of soybeans, in percent

AVERAGE %							
MOISTURE CONTENT (W.B)							
5 CO				5 PO			
8.6		8.23		8.26		7.9	
0 (Weeks)		10 (Weeks)		0 (Weeks)		10 (Weeks)	
17.22	15.15	16.85	19.23	18.90	20.59	21.37	20.33
13.32		21.64		20.53		19.85	
14.93		19.21		22.34		19.78	

Table 14. Effect of storage conditions on breakage in two varieties of wheat

AVERAGE %							
MOISTURE CONTENT (W.B)							
6 CE				6 CL			
11.75		11.03		10.99		10.50	
0 (Weeks)		10 (Weeks)		0 (Weeks)		10 (Weeks)	
1.06	1.24	1.28	1.40	.44	.426	.38	.453
1.32		1.32		.44		.46	
1.36		1.60		.40		.52	

Table 15. Effects of high temperatures in three kinds of insects

DAYS		RED FLOUR BETTLE (Triboliom Casteneum)		LESSER GRAIN BORER (Rhizoperta Dominica)		K.S RICE WEEVIL (Sitophilus oryzae)	
		N° OF INSECTS	%	N° OF INSECTS	%	N° OF INSECTS	%
1	Alive	2035	85.65	1200	95	--	
	Death	335	14.35	60	5	1700	100
	Larva	Yes		Yes		No	
2	Alive	565	25.92	600	66.6	--	
	Death	1615	74.08	400	33.4	**	100
	Larva	Yes		Yes		No	
4	Alive	2	.10	150	79.3	--	
	Death	1900	99.9	725	20.7	**	100
	Larva	Yes		Yes		No	
6	Alive	--		50	8.80	--	
	Death	2100	100	565	91.2	**	100
	Larva	No		No		No	

*Temperature 43.8°C and 55% R.H.

**Not counted (No live one was found).

Table 16. Effect of storage conditions on visual observation in grains and pinto beans.

GRAIN		VISUAL EXAMINATION WEEKS 0	VISUAL EXAMINATION WEEKS 12	STORAGE METHOD
CORN				
LOT A	1CH-1	--	Slightly paler[1]	Aeration
	1CH-2	Paler color	--	Burlap bag
	1CH-3	--	Paler yellow[1]	"
LOT B	1PI	--	Lighter Color	"
PINTO BEANS	2PB	Definitely lighter	--	Burlap bag
SORGHUM				
LOT 1	4OR-Ae	--	No difference	Aeration
	4OR	--	Slightly brighter	Burlap bag
LOT 2	4AC	Slightly lighter	Natural color	"
RICE				
Long	3LA	Paler color	--	Burlap bag
Short	3VI	Bleached slightly	--	"
SOY BEANS				
LOT 1	5CO-Ae	--	Slightly bleached color	Aeration
	5CO	Definitely paler	No grade change	Burlap bag
LOT 2	5PO	--	Slightly paler	"
WHEAT				
LOT 1	6CE	No difference	--	Burlap bag
LOT 2	6CL	No difference	--	"

1| Typical long term storage
2| -- No visual change

tasters from different countries comparing texture and flavor between samples. Representative samples of 1.25 kgs of pinto beans from 0 (Sample A) and 12 weeks storage (Sample B) were used for tasting. Before cooking they were soaked in water for 12 hours. A Mexican taster estimated the boiling time which was a function of their hardness. The boiling time in Sample B was 1.5 hours more than that of Sample A. During the cooking time kernel breakage occurred in Sample B. Table 18 shows the taste evaluation of 0 to 12 weeks storage. Taste panel scores showed that there was no significant difference in texture between Samples A and B but the flavor of the stored sample was slightly less acceptable.

With respect to milling, the product yields at 0 and 12 weeks' storage were 72.25 and 71.60% in wheat sample 6CL; 70.97 and 69.5% in wheat sample 6CE. These differences are probably not significant.

Table 19 shows the effect of storage at 44°C for 3 months on baking characteristics (loaf volume); there is no apparent effect on bread quality. The mixing time increased slightly.

Bread baking tests showed no effect of storage on loaf volume.

Millin tests of rice showed no effect of storage on head rice yield.

Table 17. Flour Characteristics of two varieties of wheat at 0 and 12 weeks of storage.

GRAIN	Weeks	M. C (%)	Ash (%)	Weight Gm.	Absorbancy. (%)	Peak Time (min)	Arrival Time (min)	Departure. (min.)	Stability (min.)	Mixing Tolerance B.U[1]	Valorimeter. B.U[1]	Malt Requirements per 100 gm flour	Protein (%)
Wheat Lot I 6CE	0	11.9	.49	48.81	60.0	6.50	3.5	9.00	5.50	80.00	61.00	.26	10.5
6CE	12	11.7	.48	48.70	58.6	6.50	1.0	16.00	15.00	20.00	68.00	.35	10.6
Lot 2 6CL	0	11.9	.47	48.81	61.0	1.50	1.0	5.50	4.50	40.00	50.00	.19	10.0
6CL	12	11.8	.45	48.76	61.0	1.50	1.0	5.50	4.50	35.00	48.00	.27	9.8

1 Brabender Units

Table 18. Taste panel scores of pinto beans.

Compared to sample **A** (stored 0 weeks) sample **B** (stored 12 weeks) scores were:

TEXTURE:	41%	better
	18	same
	41	not as good
FLAVOR:	23%	much better
	6	better
	6	same
	65	not as good
	0	much worse

Table 19. Effect of storage on baking quality of wheat

Sample	cm^3/100g. flour (Average of 2 loaves)	Mixing time, min.
65	753	4.25
66	793	5.50
67	673	6.50
68	635	8.50

CONCLUSIONS

The conclusions which resulted from this research can be summarized as follows:

1. The temperature inside the grain sacks (center) increased to room temperature in the first two weeks of storage.
2. There were no significant losses in test weight between aerated and unaerated grains.
3. Molds appeared to grow under high storage temperatures and at low equilibrium moisture content levels (and relative humidities) where mold growth has not been previously reported.
4. This finding raises doubts regarding many recommendations which have been made regarding safe grain storage conditions for tropical areas. It mandates more research to determine if molds respond to water vapor pressure rather than relative humidity.
5. Storage conditions tested produced no grade change and little change in visual appearance.
6. High storage temperatures with high relative humidity reduced the germination of all seeds.
7. Artificial drying causes more kernel damage than does storage time.
8. The high storage temperature used was fatal to most insects in six days.

9. Wheat milling yields were not drastically reduced.
10. Physical dough tests showed an increase in malt requirements as shown by an Amylograph test. Mixing tolerance was reduced. Farinograph times changed on one sample (6CL).
11. Baking tests showed no effect of storage on wheat quality.

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LITERATURE CITED

1. Amen, R. D. 1946. The concept of seed dormancy. Wallerstein LAB. Commun., 27:7-18.

2. Ayerst, G. 1965b. Determination of water activity of some hygroscopic food materials by a dew-point method. J. Sci. Food Agr., 6:71-78.

3. Bailey, C. H. 1921. Respiration on Shelled Cron. Minn. Agr. Exp. Sta. Tech. Bull. 3.

4. Campbell, J. D. and C. R. Jones. 1949. On the physical basis of the response of endosperm density to change in moisture content. II. Reversibility of endosperm density of drying in relation to behavior of whole wheat grains. Cereal Chem., 26:267-286.

5. Christensen, C. M. 1957. Fungi on and in wheat seed. Cereal Chem., 28:408-415.

6. Christensen, M. 1974. Storage of cereal grain and their products. Published by the American Association of Cereal Chemists, St. Paul, Minnesota.

7. Chung, D. S., and H. B. Pfost. 1967b. Adsorption and desorption of water vapor by cereal grains and their products 111. A Hypothesis for explaining the hysteresis effect. Trans. Americ. Soc. Agr. Eng. (St. Joseph, Mich.), 10:555-558.

8. Cotton, R. T., H. H. Walkclen, G. D. White, and D. A. Wilbur. 1960. Causes of outbreak of stored grain insects, 35 p. Kansas. Agr. Exp. Sta. Bull. 416.

9. Cotton, R. T. and T. C. Frankenfeld. 1945. Protected stored seed from insects attack. U. S. Department Agr. Bur. Entomol. Plant Quarantine Circ. E-677.

10. Hall, D. W. 1970. Handling and Storage of food grains in tropical and subtropical areas. F. A. O., Rome.

11. Earle, P. L. and N. H. Celglske. 1949. Factors causing the checking of macaroni. Cereal Chem., 26:267-286.

12. Brown, Edgar. 1947. Dormancy and the effect of storage on oats, barley and sorghum. U. S. D. A. Tech. Bull. 953.

13. Carter, Edward P. and George V. Young. 1944. Effect of moisture content temperature and length of storage on the development of

"sick" wheat in sacked container. Cereal Chem., 22:418-428.

14. Gay, F. J. and F. N. Ratcliff. 1941. The importance of Rhizopertha dominica as a pest of wheat under wartime storage conditions. J. Council Sci. Ind. Research (Australia), 14:173-180.

15. Grosh, Gordon M. and Max Milner. 1959. Water penetration and internal cracking in tempered wheat grains. Cereal Chem., 26:260-273.

16. Bottomley, H. A., Clyde M. Christensen and W. F. Geddes. 1950. The influence of various temperatures, humidities and oxygen concentrations on mold growth and biochemical changes in stored yellow corn. Cereal Chem., 27:271-295.

17. Hall, C. W. 1957. Drying farm crops. Pub. Agriculturing Assoc. Inc., Reynoldsburg, Ohio, 339 pp.

18. Halliday, D. and F. I. Nwankwo. 1963. Moisture uptake of bagged groundnuts at port narcount. Nigerian Stored Prod. Res. Inst. A. Rep. 1963., tech. rep. No. 9, 91-95.

19. Hummel, B. C. W., C. S. Cuedent, C. M. Christensen and W. F. Heddess. 1954. Comparative changes in respiration, viability and chemical composition Cereal Chem., 31:143-150.

20. Tervet, Ian W. 1944. The influence of fungi on seed viability and seedling vigor of soybeans. Phytopathology, 35:3-15.

21. Wang, Jaw-Kai. 1958. Theory of drying. Michigan State University Unpublished PhD Dissertation.

22. Anderson, J. A. and A. W. Alcock. 1954. Storage of Cereal Grains and their products. Published by the American Association of Cereal Chemists. St. Paul, Minnesota.

23. Babbitt, J. D. 1940. Observations on the permeability of hygroscopic materials to water vapor. The Nat. Research Counc. of Canada 18, sec. G:105-121.

24. Joffe, A. 1958. Moisture migration in horizontally stored bulk maize. The influence of grain infesting insects under South African conditions. S. Afr. J. Agric. Sci., 1:175-193.

25. Olafson, Jon H., C. M. Christensen and W. F. Geddes. 1954. Grain Storage Studies XV. Influences of Moisture content, commercial grade and maturity of the respiration and chemical deterioration of corn. Cereal Chem., 31:333-340.

26. Kreyger, J. 1972. Drying and storing grains, seeds and pulses in temperate climates. IBVL P. O. Box 18, Wageningen Holland.

27. Milner, Max and W. F. Geddes. 1945. Grain Storage Studies II. The effect of aeration, temperature and time of the respiration of

soybeans containing excessive moisture. Cereal Chem., 22:450-484.

28. Milner, Max and W. F. Geddes. 1945. Grain Storage Studies III. The relation between moisture content, mold growth and respiration of soybeans. Cereal Chem., 23:225-245.

29. Milner, Max and J. A. Shellenberger. 1953. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem., 30:202-212.

30. Milner, M., C. N. Christensen and W. F. Geddes. 1947. Grain Storage Studies IV. Wheat respiration in relation to moisture content, mold growth, chemical deterioration and heating. Cereal Chem., 24:182-199.

31. Navarro, S., E. Donahaye and M. Calderon. 1969. Observation on prolonged grain storage with forced aeration in Israel. J. Stored Prod. Res., 5:73-81.

32. Teter, N. C. and C. W. Roane. 1958. Mold impose limitation in grain drying. Agr. Eng., 24-27. (March)

33. Person, N. K., Jr. and J. W. Sorenson, Jr. 1966. Penumatic handling of sorghum grain. Trans. of the ASAE, 9:238-241.

34. Pixton, S. W. and S. Warburton. 1971. Moisture content, relative humidity equilibrium relationship of some cereal grains at different temperatures. J. Stored Prod. Res., 6:283-292.

35. McGinty, Ralph J. 1970. Development of a standard grain breakage test. U.S.D.A. ARS., 51-34. (February).

36. Thompson, Ralph A. and George H. Foster. 1961. Stress cracks in artificial dried corn. AMS-434 U.S.D.A.

37. Thompson, Ralph A. and George H. Foster. 1963. Stress cracks and breakage in artificially dried corn. U.S.D.A. Mar. No. 631.

38. Roberts, E. H. 1960. The viability of cereal seed in relation to temperature and moisture. Ann. Bot. U.S., 24:2-31.

39. Robertson, D. W., C. C. Fifield and L. Zeleny. 1939. Effect of relative humidity on viability, moisture content and respiration of wheat, oats, barley, corn, rye, sorghum and soybeans. J. Amer. Soc. Agron., 35:786-795.

40. Robinson, W. 1926. Low temperatures and moistures and factors in the ecology of the rice weevil, sitophilus oryza L. and the granary weevil, sitophilus granarious L. Minn. Agr. Exp. Sta. Tech. Bull. 41.

41. Katz, R., N. D. Colling and A. B. Cardwell. 1961. Hardness and moisture content of wheat kernels. Cereal Chem., 38:364-368.

42. Semeniuk, P. A. 1954. Microflora. pp. 77-151. In J. A. Anderson and A. W. Alcock (eds.) Storage of cereal grains and their products. America Assoc. Cereal Chem. Inc. St. Paul, Minn.

43. Snow, D., M. H. G. Crichton and N. C. Wright. Mold deterioration on feeding stuffs in relation to humidity of storage I. The growth of molds at low humidities. Ann. Applied Biol., 31:102-110.

44. Block, S. S., R. Rodriquez-Torrent, M. B. Cole and A. E. Prince. 1962. Humidity and temperature requirements of selected fungi. Technical Paper Series 16. No. 16. Engineering Progress of the University of Florida.

45. Kiesselbach, T. A. 1939. Effect of artificial drying upon the germination of seed corn. Jour. Amer. Soc. of Agr. pp. 480-496.

46. Van Arsdel, W. B. 1947. Approximate diffusion calculations for the falling-rate phase of drying. Trans. Am. Inst. 43 No. 1, pp. 13-21.

47. Went, F. W. 1957. The experimental control of plant growth, p. 261. Cronica Botonica Co., Mass., U.S.A.

48. Scott, W. J. 1957. Water relation of food spoilage micro-organism. Adv. Food. Res. 7.

49. Bilanski, W. K. 1966. Damage resistence of seed grains. Trans. of the ASAE, 9:360-363.

50. Togashi, K. 1949. Biological character of plant pathogens temperature relations. Tokyo, Meibundo, p. 478.

51. Heinz Sorger-Domenigg, L. S. Cuedent and W. F. Geddes. 1955. Grain Storage Studies XX. Relation between viability, fat acidity, germ damage, flourescence value and formazan value of commercial wheat samples. Cereal Chem., 32:490-506.

APPENDIX A

SAMPLE DESIGNATION

Nomenclature

First No. indicates type of grain

1 = Corn

2 = Pinto Beans

3 = Rice

4 = Sorghum

5 = Soybeans

6 = Wheat

Varieties: First and second letters indicate the variety

For Rice:		Labonnet (long grain) = LA
		Vista (medium grain) = VI
	Corn:	Pioneer 3184 = PI
		Mixed = CH-1 = Artificial drying (Aeration)
		= CH-2 = Natural drying (sac)
		= CH-3 = Artificial drying (sac)
	Sorghum:	Oro = OR
		Acco = AC
	Soybeans:	Columbus = CO
		Pomona = PO
	Wheat:	Cloud = CL
		Century = CE

Pinto Beans: OU = PB

Types of Experiment

Third letter

A = Milling

B = Baking

C = Breakage

D = Stress Crack

E = Chemical

F = Germination

G = Mold - insects

Numbers of Test

Fourth letter

Week 0 = Z

7 = Y

12 = X

NOTE: In Pinto Beans the second number indicates that it is aerated.
Example: 51CO

1 CH-1 in corn indicates aeration
Ae indicates aeration

HIGH TEMPERATURE AND HIGH HUMIDITY GRAIN STORAGE

by

GABRIEL RENGIFO

B. S., Universidad de America, Bogota, Colombia 1973

AN ABSTRACT OF A MASTER'S THESIS

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This study is concerned with problems of grain storage in tropical areas where the temperature and relative humidity are generally above 70°F and 70% respectively. Most common grain storage molds grow vigorously at these conditions. Grain can be dried to a low moisture content where the air surrounding the grain will inhibit mold growth but stored grain will equilibrate with the surrounding air in time.

If air at 90°F and 90% relative humidity is heated at constant absolute humidity to 110°F the final relative humidity would be about 60%. Published literature indicates that no grain storage molds should grow at 60% relative humidity. To test the practicality of using heated air for grain aeration the studies reported were made.

Corn, wheat, rice, sorghum, beans and soybeans were stored in sacks and aerated bins for 12 weeks at 44°C and 55% relative humidity.

The results can be summarized as follows:

1. The temperature inside the sacks (center) increased to the air temperature in the first two weeks of storage.
2. There were no significant losses in test weight between aerated and unaerated grains.
3. Molds appeared to grow with the temperature and relative humidity used. Possibly, molds respond to water vapor pressure.
4. Germination decreased on all grains.
5. Single, multiple and checked stress cracks were developed in corn.
6. Breakage in small grains were less than corn and soybeans.
7. There was no evidence of insects in grains and soybeans at those conditions and almost all test insects placed in the test chamber died within 6 days.
8. Palatability and texture of pinto beans was not drastically affected

by storage.

9. Wheat milling yields were not drastically reduced.

10. Physical dough tests showed an increase in malt requirements as shown by Amylograph test. Mixing tolerance was reduced. Farinograph times changed on one sample (GCL).