The effect of three drying temperatures on the germination of corn harvested at three stages of maturity
by Josiah Wobil

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agronomy
Montana State University

Abstract:
Seed corn was harvested at 3 moisture levels, 41.2%, 33.7%, and 27.1%, and each dried at temperatures of 110°F, 120°F, and 130°f.

The effects on germination of percent moisture at harvest and drying temperature were investigated. The influence of height of grain in the drying column and the level in the drying column from which corn was removed were also studied.

The dried seed was subjected to the process of accelerated aging. The effect of aging and the effect of the various treatments on the germination of the aged seed were then investigated.

With respect to the unaged seed, temperature, percent moisture at harvest and sampling level, all significantly influenced germination. There was a linear reduction in germination with increase in percent harvest moisture. Temperature affected germination in a similar manner; the reduction in percent germination was, however, more pronounced as temperature was increased from 120°F to 130°F.

The temperature effect was also manifested by the influence of sampling level on germination.

The ability to withstand higher drying temperature increased as percent moisture at harvest decreased. Height of grain in the drying column was found to influence germination at high harvest mositure.

Aging was found to lower percent germination. The general effect of aging as related to each of the significant treatments was to accentuate, almost similarly, the influence of these treatments in the unaged seed.

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A thesis submitted to the Graduate Faculty in partial
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ABSTRACT

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INTRODUCTION

Under favorable conditions, most farmers in the United States harvest corn which is intended for seed at a moisture content of about 25% and rarely above 30%. The corn is dried on the cob as rapidly as possible to less than 14% moisture before being put into storage.

Under these conditions good germination and high quality are obtained if storage conditions are adequate.

Drying of seed is done for the following reasons:

1. To preserve the seed from physical or chemical changes brought about or enhanced by the presence of excess moisture.

2. To bring the seed to the standard commercial requirement of moisture content.

3. In some cases, to remove the crop from exposure to field conditions, that might impair the quality of the seed. Such adverse field conditions are shattering, insect infestation, precipitation, and frost.

The most widely used method of drying is a unit which provides heated air under pressure. The heated air is forced through the seed, and, by virtue of its lowered vapor pressure, it picks up moisture from the seed.

In the drying of grain intended as feed, temperatures are not very critical, but the selection of a proper drying temperature is the most important prerequisite in seed drying requirements. While too low a temperature will make the drying operation inefficient, too high a temperature may exert certain deleterious effects on the seed and particularly on the embryo. Since the importance of seeds, unlike feed grain, lies in their ability to germinate and grow vigorously into normal plants, any impairment of the embryo is to be avoided.

As already indicated, one of the reasons for artificial drying of seeds is to remove the crop from exposure to certain undesirable field conditions. In many agricultural areas, therefore, corn is sometimes harvested at a moisture level far higher than would be desired in an effort to prevent total loss of crop due to certain field conditions. Thus, in the northern states of the U.S., corn might be harvested earlier than usual in an attempt to prevent frost injury.

The author is motivated in this study by conditions prevailing in Ghana, his home country, where the problem is not one of frost injury but rather of precipitation during the time of harvesting and processing. In Ghana, traditionally two corn crops are harvested each year. The first crop is harvested by early August and the second crop is planted early in September.

The seed harvested from the first planting may not necessarily be used to plant the second crop, as seed from the previous year's harvests would normally be readily available.

Since artificial drying is practiced on a very limited scale most of the corn is dried in the sun. Thus, the mature corn remains unharvested until dry enough to be hand-shelled. The shelled corn is further dried on drying slabs until dry enough to go into storage. Therefore, at the time of harvest the corn is generally at a moisture content of about 18%.

The second planting follows the first harvest very closely and only a short period is available for the harvesting and processing of the first crop and the preparation of land and planting of the second crop. This short period is also one of intense rainfall and cloudiness. The net result of this state of affairs is as follows:

1. Field conditions, both aerial and edaphic become very unsuitable for work in the field both with regard to preparation of the land for the second corn crop and the harvesting of the first in early August.

2. The frequent precipitation and cloudiness cut down the period that the traditional method of drying can be employed. Some corn may, therefore, eventually have to go into storage at a moisture level not suitable for storage, while some may go moldy on the drying slabs.

3. The greater portion of the second season rainfall falls in September and October. Therefore, any delay in planting usually exposes the plants to drought conditions at about tasseling stage and this may lead to crop failure.

The foregoing conditions do not pose problems for the ordinary peasant farmer whose holding rarely exceeds five acres. But any fair-sized farm really does face serious problems. Some farms may try to forego a second planting and concentrate on processing the first crop. However, this constitutes an inefficient use of land and other capital investments.

Perhaps a better solution would be to harvest the first crop earlier and dry the immature corn by artificial drying so that there is time enough to devote to preparation of land and planting of the second crop.

The general purpose of the study reported herein, was to determine the suitability of immature corn for seed purposes. The principal objectives were as follows:

1. To design and construct a pilot corn drying unit satisfactory for drying ear corn to be used for seed.
2. Using this drying unit, to dry corn harvested at three levels of moisture, each being subjected to three temperatures. Thereafter to determine the effect of both harvest moisture and drying temperature on the germination of the dried corn seed.
3. To determine if the level in the drying column at which seed corn is dried (referred to in this study as sampling level) has an effect on the percent germination.
4. To determine the influence of height of grain in the drying

chamber on germination.

5. To determine the storability of the various corn samples through the technique of accelerated aging.

LITERATURE REVIEW

The suitability of immature corn for seed has been investigated by many workers. Soon after artificial drying became widespread and seed corn could be harvested earlier, it became necessary to know safe temperature limits for drying and also any effect drying temperature would have on the seed, especially immature one.

Duncan and Marston (1) [1]harvested seed corn in different stages of maturity, i.e., milk, soft dough and hard dough stages. Samples of all three stages were placed on the laboratory table and allowed to dry at 68°F room temperature. All samples germinated 100 percent.

Similar samples were dried in an oven with a constant temperature of 112°F. Soft dough samples were dried for a period of 18 hours and hard dough samples were dried for a period of 24 hours. While this treatment did not seem to lower the germination ability of corn in the soft and hard dough stages, germination of corn in the milk stage was lowered to about 40%.

However, when the milk stage sample was dried with a temperature of 95°F for 36 hours the germination was raised to 90 percent.

Dimmock (4) did extensive investigation into the effect of maturity and artificial drying upon the quality of seed corn. He used samples ranging from 20 percent to 58 percent moisture at time of harvest and dried them at temperatures ranging from 108°F to 150°F. Comparable samples were also air dried as a check.

1/ Figures in parenthesis refer to literature cited on page 46.

Dimmock observed that immaturity had definite effects upon the appearance of the seed. The kernels were small, shrunken, dull, opaque, and the pericarp was often blistered. Artificial drying of immature seed seemed to increase the blistering of the pericarp and the seed took on a bleached appearance. He found that in all artificially dried samples, radicles appeared at a faster rate during germination than air-dried samples. The appearance of radicles in the aartificially-dried samples was more rapid in the immature samples having 48 and 59 percent moisture at harvest. However, twelve hours after the first observations were made, the more mature samples had equalled the count and, thence, the rate of appearance of radicles was the same in all samples, both artificially-dried and air-dried. He found plumules, on the other hand, to develop most rapidly in the more mature, low-moisture kernels. In this case, the immature kernels, especially those artificially dried, had the lowest plumule count throughout. Immaturity of seed was found not only to retard development of secondary or lateral roots but also make for less vigorous seedlings. Immaturity was also found to retard field emergence. This effect was further accentuated by artificial drying. While the air-dried immature kernels at 48% moisture produced 93% emergence in 12 days, it required 14 days to produce 15% emergence in the corresponding artificially-dried samples. Dimmock surmized from such a wide difference between these two samples that the temperature of drying may have been too high for the immature corn, resulting in either or all of the following:

1) direct injury to the meristematic cells of the embryo
2) injury to those cells of the scutellum responsible for the secretion of diastatic and other enzymes
3) total or partial destruction of the enzymes themselves, or lowering of their activity.

Dimmock also found artificial drying to have an effect on germination of mature corn. An air-dried sample which contained 27% moisture at harvest required 8 days for 100% seedling emergence. An air-dried 32% moisture sample required 9 days for 98% seedling emergence. On the other hand, artificially-dried samples at the same moisture levels required 15 days to attain 98% seedling emergence.

Dimmock concluded from his work that drying at temperatures ranging from 130 to 150°F for periods up to 24 hours proved injurious to the germination and seedling emergence of well-matured corn which had 22.5 to 26% moisture at harvest. He also found that shelled corn suffered greater injury than the ear corn at all temperatures and all periods of drying.

Harrison and Wright (7) concluded that drying with forced air at temperatures between 104°F to 113°F is not injurious to ear corn. At 122°F, ear corn was appreciably damaged and at 140°F, almost all germs were damaged while a temperature of 158°F completely killed all germs.

Sprague (12) worked with seed corn, the moisture percentage of which ranged from 83.79 for the first harvest to 23.33 for the last. He planted his germination samples in sand and kept daily records of emergence until germination was completed. He found that the germination percentages for the samples determined immediately after harvest ranged from 0 to 100. The germination percentage, however, improved for all samples the longer they were kept or the drier they became. He summarized that after-ripening of immature corn is achieved by the loss of moisture. While exhibiting a great variability in time of germination immediately after harvest, immature corn, he said, increases its germination ability and decreases the variability in time of germination, as it dries out. He stated that the moisture content of immature seeds must be reduced to approximately 25% before normal germination occurs. Corn kernels, he noted, require a minimum of approximately 35 and 69% moisture in whole grain and embryo, respectively, before germination can occur.

Sprague thought that the mechanism that is responsible for inhibiting germination in freshly harvested corn is centered in the scutellum.

Koshimizu (11) reported in his work that, although it is true that a decrease in moisture content brings about germination, he disagreed with Sprague as to the mechanism involved. He attributed the effect to a consequent increase in nutrient solution and oxygen.

He excised embryos of unripe corn seeds and found that they germinated more quickly than intact seeds. He also discovered that endosperm juice of unripe seeds inhibited germination. He, therefore, surmised that drying of the seed might change the nature of the inhibiting substance so that it no longer would inhibit germination.

Walker (13) found that corn harvested 31 days from silk stage and older achieved from 90 to 100% germination in 9 days. He surmised that good germination and strong plants can be expected to be produced by immature corn that has been well cured and carefully stored.

Wileman (14) dried samples of corn harvested at moisture levels ranging from 35% and above down to less than 20%. He used drying temperatures ranging from 100°F to 140°F at 10° intervals.

He found that the higher the initial moisture content of the corn, the lower the drying temperature must be to avoid deterioration. Corn with an initial moisture content of 35% or more dropped rapidly in germination when dried at air temperatures as high as 120°F. Corn with a moisture content of 20 to 25% suffered no appreciable reduction in germination when subjected to a drying temperature of 120°F. A temperature of 130°F did not seem to appreciably harm corn with less than 20% moisture.

Wileman also found that drying with low temperatures (about 100°F) can lead to fungus growth which will in turn retard germination. This is due to the fact that fungus can tolerate low drying temperatures.

Wileman tried to determine if there were any differences in heat tolerance between the varieties of corn that he used. He concluded from his data that any differences that might exist are too insignificant and of no practical consequence within the range of air temperatures used.

In his article on heat for control of cereal insects, Goodwin (6) remarked that corn heated to a temperature of 140°F for almost 2 days germinated almost as well as an unheated sample from the same lot. This temperature is very high and his findings in this respect do not agree with those by most other workers whose general concensus of opinion is that even 130°F will decidedly impair germination of seed corn. It seems that his primary objective being the recommendation of suitable temperatures for insect control, he might have been less enthusiastic about the effect these temperatures might have on the germination of corn seed.

De Ong (3) working with various seeds, also stated that temperatures of 100°F to 155°F for 5 hours, 124° to 154°F for two hours and 125°F for eight hours gave germination of 86, 88, and 94% , respectively, for the bean varieties. For the grains including corn he observed even better germination. He concluded that the effect of such high temperature on grains is too small as to be negligible. It is known, however, that wheat and barley would not be injured by temperatures that would seriously affect corn, the latter being more sensitive to heat than either wheat or barley.

As Kienholz (8) pointed out, most of the entomologists did not work with carefully controlled temperatures or periods of exposure, and they seldom gave details as to the moisture content of the seed, the method of heating, etc. Kienholz noted that the resistance of corn to high temperatures varies inversely as its water content at the time of heating.

De Ong's temperature ranges were too large, and if indeed he obtained such high germination percentages, then it is probable that the lower limits of the ranges were operative most of the time.

De Ong's results seem to have much more veracity, however, than Goodwin's. De Ong's periods of drying were short. There is a period of heating during which the evaporative cooling of the seed is sufficient to offset any injurious effect of high temperatures, until a critical stage is reached. This coupled with the chance that the lower limits of his temperature ranges might have been operative for most of the time, might explain the results De Ong had.

Alberts (1) determined percentage of shrinkage, shelling, and germination at different stages of maturity including early milk stage, late milk stage, dough stage, initial glaze stage, and full dent stage. Shrinkage, being the reduction in seed weight, was determined by taking the difference between the weight of ears at the time of harvesting and the beginning of germination test when the seed had been dried. Shelling percentage was taken to be the ratio of the weight of grain to the total weight of ears.

Alberts found shrinkages as high as 80% in the early milk stage. Shrinkage was lowest in corn that was harvested after it was fully dented. Shrinkage in this case was as low as 36%. Shelling percentage increased from 25% in the early milk stage to 85% in the full dent stage. There was little difference in shelling percentage between the beginning of the glaze stage and the full dent stage. The same can be said, but to a lesser extent, with respect to shrinkage. However, with respect to germination, all seeds harvested from dough stage until full dent stage had equally good germination percentages, i. e., from 96 to 99. Poorest germination was obtained with seeds harvested in the early milk stage, 14 and 75% being the figures obtained for the two varieties used.

In their investigation into the maturity of seed in relation to yielding ability and disease infection, Koehler et. al., (10) found that germination was normal in the late milk stage and just slightly below normal in the milk stage though the percentage of kernels germinating strong was very low; 7.7 and 25.7% for the milk and late milk stage, respectively. The percentage increased to around 70 for seed harvested in dent, mature and husking stages. They also found that the weight per kernel determined at 12% moisture, weight per bushel, and specific gravity all increased with maturity.

Koehler et. al., recommended that in case of emergency, corn harvested in milk stage, when the corn has attained less than 1/3 the moisture it would attain if allowed to mature, can be used as seed, if handled properly and as little mechanical injury as possible is inflicted. The seed coat complex, at this stage, is very susceptible to injury. They also reported that such seed cannot be expected to give as good results as mature seed insofar as field stand, disease resistance or acre yield are concerned.

Since mature seeds perform the best, they suggest that farmers try to plant early-maturing strains that would mature properly under their various conditions.

The purpose of drying is to bring the moisture content of the grain to a level safe enough for storage. There is little or no purpose in reducing the moisture content below the safe level. To do so would be uneconomical and useless.

It has been demonstrated by many workers that very low moisture levels achieved by safe drying temperatures, while not increasing the germination ability of corn, do not lower it.

Harrison and Wright (7) dried corn at 113°F for 120 hours and reduced the grain moisture content down to 3.4%. They obtained a germination of 95% and concluded that the amount of dessication did not affect the germination.

Kiesselbach (9) dried seed corn at a temperature of 107°F for 35 days, and, thereby, reduced the moisture content to 4.4%. This seed germinated 98%, and among his conclusions, he stated that the permissible range of moisture for safe processing and storage is about 5 to 14%.

It appears from the foregoing that when corn is dried at a safe temperature the amount of dessication is of no consequence so far as germination is concerned. However, these studies seem not to have investigated the effect of dessication when immature seed is used. In this respect, the work done by Dimmock is worthy of note.

Dimmock (4) found no lowering of germination by the length of drying on corn with initial moisture content of less than 35.1%, but there was considerable lowering of germination of corn with initial moisture content of 44.6%. He dried three samples, A, B, and C, having initial moisture contents of 25.2, 35.1 and 44.6%, respectively, down to 2%. While this amount of dessication had almost no effect on the germination of the A and B samples which had almost 100% germination, C's germination fell from 100 to between 81 and 71%. Some investigators also believe that extreme dessication at safe temperatures can induce dormancy in some varieties and also increase susceptibility of seed to mechanical damage.

It was a widely held notion that even with safe temperatures, it is not desirable to dry at a fast rate, but this has been demonstrated by Harrison and Wright (7) not to be so. Using about 40°C they dried corn to about 12% moisture at a faster rate so that drying was completed in 72 to 96 hours. Germination of the corn so heated was 95 to 99%. Field emergence was as good as corn dried slowly.

There seems to be lack of literature on the keeping quality or storability of immature corn and especially immature corn subjected to artificial drying. The writer intended to investigate this field but owing to the limited time available for this study, he resorted to the technique of accelerated aging.

This technique allows for telescoping the time element involved in determining the relative life span of seed lots under various storage conditions. The physiological processes that take place during the deterioration of seed are similar under various conditions; the only difference is that the rate of deterioration varies. Thus, one can subject seed samples to high temperatures and 100% relative humidity and obtain a level of deterioration that would normally require months to achieve.

The technique used by Charles Baskin (2) was adopted. He exposed small quantities of seed corn to a temperature of 40-45°C and 100% relative humidity for 60 hours. Identical samples were stored under open storage at room temperature. His results are shown in Appendix table 14. In his study, the reduction in germination as a result of open exposure to 45°C and 100% relative humidity for 60 hours was essentially the same as the reduction brought about as a result of open storage for 18 months. This means that accelerated aging produced "18 month old" corn in 60 hours.

MATERIALS AND METHODS

A pilot-type electric drier was constructed, consisting of an 8-inch squirrel cage fan, a sheet metal cage, three metal housings. Each housing contained a "Lennox" duct heater, and the three housings were connected by a series of ducts to three pairs of wooden drying columns.

The squirrel cage fan, driven by a 1/3 h.p. motor was capable of delivering 1000 cubic feet of air per minute from an opening of 16½" x 15". Riveted to this opening was an 18 inch long cage made of 28 gage galvanized metal. The riveted end measured 16" x 15". The other end, measuring 22" x 16" was joined to three housings made of the same kind of material as the cage. Each housing was 16" high and 7" wide. The three were joined together side to side.

The free end of each housing was sealed with a 16" x 7" metal sheet. Two openings, each 6½" x 6½" were cut into each of these sheets to accomodate take off, with one end 6½" x 6½" and the other end having a 6" diameter.

An opening was made on top of each housing and a "Lennox" duct heater, about 15½" high was lowered through this opening into the housing.

The paired wooden drying columns were constructed using 3/4" hardwood. Each pair of columns consisted of two boxes each measuring, on the inside, 8" x 8" cross section and 72" high and the two shared a common wall.

An 8" x 8" wire mesh was slatted on the lower end of each box, 12" from the bottom, so that an air chamber of 8" x 12" was delimited at the bottom of each column.

To prevent easier passage of air along the corners of the columns, a 60" long piece of wood with triangular cross-section was nailed into each corner. Each triangular cross-section was carefully cut to provide a good fit. The sides bordering the right angle were 3" each so that the effective cross-sectional area of each box was reduced from 64 square inches to 46 square inches.

The bottom part of each column was also provided with a thermostat to control the temperature of the air entering the column, and a thermometer to calibrate the thermostat.

The two 6-inch holes in the lower portion of each column were connected by a series of 6 inch ducts to two corresponding take-offs on the housings containing the heaters. Two take-offs from one heater, therefore, connected with one pair of drying columns. Thus, it was now possible to blow air over a heater and have the heated air channeled through two ducts into two paired columns. Each duct system was provided with a baffle so that air flow could be controlled.

A 12-volt circuit required to operate the three thermostats was provided by a 12-volt transformer. Each of the heaters was provided with a 240-volt circuit, so wired that in case of overheating as a result of fan or thermostat failure, the whole system would switch off automatically and not restart unless manually reset.

All joints, both in the sheet metal work and in the wooden boxes were caulked and/or taped to prevent escape of air.

Round doors, each 6 inches in diameter, were made at the back of each column, just above the wire screen to facilitate removal of corn samples from the bottom.

The columns were designated as A_1 and A_2, B_1 and B_2, C_1 and C_2. Columns A_1, B_1, and C_1 had thermometers inserted in holes made at the 12 inch and the 48 inch levels (measured from the top of the wire screen). Columns A_2, B_2 and C_2 had thermometers in holes made at the 12 inch and 60 inch levels. This was done so that temperature variation in the columns could be observed throughout the experiment.

The equipment was trial-run without corn to set the temperatures and the air flow. The first trial-run showed that the air flow measured by a velometer was about 100 times more than desired. As a result, the heaters barely glowed; and the baffles were inadequate to reduce this flow to any appreciable degree.

It was necessary to reduce the opening through which air was drawn into the fan. This was done by riveting two appropriately shaped galvanized sheets to the two side openings of the squirrel cage fan. These metal sheets were supplemented with pieces from a heavy plastic. The result was a reduction in air flow to approximately 8 c.f.m. for each column.

It was necessary to adjust the air flow to the same rate in all the columns so that differences noted in the temperature and moisture variations could be attributable to differences in heights of drying columns and not to air flow rates. However, air flow rates were not exactly the same as slight increases or decreases were necessary to make the temperature in each paired column the same. These minute adjustments were accomplished by adjusting the baffles.

Temperature range for the various drying columns were as follows:

Column	Upper Limit	Lower Limit	Mean Temperature
A_1A_2	114°F	106°F	110°F
B_1B_2	124°F	116°F	120°F
C_1C_2	134°F	126°F	130°F

Hybrid corn, grown at the Agricultural Experiment Station at Huntley, Montana was harvested at three stages of moisture or maturity. First, when it had obtained an average of 41.2% moisture, then at 33.8% moisture, and finally at 27.1% moisture.

Each harvest was handled in the following manner: ears at approximately the same stage of maturity were selected in the field by visual appraisal. Ears were then dehusked by hand. Representative ears were shelled by hand to obtain moisture portions. Moisture content was determined using a Motomco Moisture meter. The moisture at harvest was based on the average of five shelled samples.

Samples from the freshly harvested corn were taken to the laboratory where germination tests were performed after exposure to room temperature for 1, 7, and 11 days.

All ears to be artificially dried were manually broken into about 3 inch pieces to insure good packing of the material in the columns. Drying columns A_1, B_2, and C_1 were filled to the 48 inch mark while A_2, B_2, and C_2 were filled to the 60 inch mark.

The fan, and then the heaters, were switched on, and drying commenced.

The equipment was shut down when sampling showed that moisture percentage of corn taken from the upper level of column A_2 was about 14%. It was assumed that column A_2 receiving the 110°F and having a 60" drying height would be the least dry at the end of the drying period.

The following data gives the drying periods for the three runs:

Moisture at harvest-%	Drying period-hours
41.2	92
33.8	85
27.1	68

During shut down, the heaters were switched off first and air was allowed to blow through the column to cool the corn.

After drying, test samples were taken in the following manner: samples representing the upper-most portion of each column was obtained by reaching into the column from above and removing 12 cob pieces.

Samples representing the lower portion were removed through the door at the bottom of each column.

A shelled portion of each sample was obtained and its moisture content determined by the "Motomco" Moisture meter. Each sample was then put into a moisture-proof plastic bag to maintain the original moisture content. Replicated germination tests of 100 kernels each were performed on all samples immediately after drying.

Accelerated Aging. Each sample was subjected to the process of accelerated aging as described by Baskin (2) to predict how well the various samples would store under open storage. This procedure was adopted because the time available for this work was not adequate to allow open storage of the samples for any appreciable length of time. About 100 grams of each sample were put into a glass dish and kept in a chamber with a constant relative humidity of 100% and temperature varying between 40^{o} and $45^{o}C$ for 60 hours. Germination tests were performed on these samples after this treatment.

All germination tests were made between paper towels using 100 kernels. Pfeiffer germination units were maintained at $25^{o}F$ constant temperature. The number of normal seedlings was scored at a final 7 day count.

RESULTS AND DISCUSSION

The percent germination of freshly harvested, undried corn seed was closely related to the number of days it was stored before germination began, Table 1. Also, the higher the percent moisture at harvest, the greater the decrease in the percent germination, and in association with storage time, the greater the variation in percent germination. These data agree with findings reported by Sprague (12). As Sprague pointed out, after-ripening is required in corn seed before it germinates. This after-ripening is brought about by loss of moisture. The longer the seed was stored, the drier it became. Corn harvested at a lower moisture level required less after-ripening and, therefore, was able to attain high germination percentage earlier than corn harvested at a higher moisture level.

The time required for drying corn seed to below 14% moisture decreased as the moisture percentage at harvest decreased. The final grain moisture percentages of all samples at the end of the drying period are given in Table 2. It is evident from Table 2 that in all the drying columns, the lower levels had drier grain than the upper levels at the end of the drying period. The difference in the final moisture percentages of the upper and lower levels decreased as the moisture at harvest decreased and as drying temperature was increased.

The lower levels were drier at the end of the drying period because they were nearer the source of heat, thus warmer. As the corn at the lower level dries, the mositure lost due to evaporation partly

Table 1. Relationship between germination percentage of freshly harvested seed corn and days exposed to room temperature before germination.

Moisture at harvest	Number of days kept before germination	Germination percentage
41.2	1	39
	7	87
	11	100
33.8	1	66
	7	91
	11	100
27.1	1	88
	7	100

Table 2. Percent moisture at the end of drying periods of seed corn harvested at three moisture levels and dried at three temperatures.

Moisture at harvest %	Drying temperature °F	Percent moisture at end of drying period			
		Samples from 48" columns		Samples from 60" columns	
		Upper levels	Lower levels	Upper levels	Lower levels
41.2	110	14.1	10.1	15.2	10.3
	120	13.2	9.3	14.3	9.1
	130	11.1	8.5	13.0	8.7
33.8	110	13.9	11.9	14.0	12
	120	13.0	10.6	13.1	11
	130	10.8	9.7	10.8	9.8
27.1	110	13.5	12.8	13.0	12.1
	120	12.1	11.7	12.5	11.9
	130	9.9	9.0	10.1	9.5

condenses at the upper levels as the heated air reaches the grain in the upper level which is cooler. This moisture will be removed as the temperature rises in the upper levels. This explains, in part, why the difference in percent moisture between the upper and lower levels was greater for corn with higher harvest moisture percentage and also for drying columns with 60" depth of grain.

Analysis of variance, based on a fixed statistical model (Appendix, Table 12) of percent germination for unaged seed indicates the following: the main effects, percent seed moisture, drying temperature and sample level all significantly influenced germination; height of grain in the drying column did not affect germination. Considering the interactions among these factors, all the 3-way interactions and the 4-way interactions are non-significant. This indicates that when one or more factors are considered, the response to levels of one factor is consistent when taken over all levels of other factors. The height x level and the temperature x height interactions are non-significant; these results are interpreted in the same manner as the 3- and 4-way interactions.

The moisture x temperature, moisture x height, moisture x sampling level and temperature x sampling level interactions are all statistically significant. This reflects, respectively, a non-uniform germination response of moisture levels taken over drying temperatures, Figure 1, of moisture levels taken over heights of grain in column, Figure 2, of moisture levels taken over sampling levels, Figure 3, and of drying temperatures taken over sampling levels, Figure 4.

Runs (replications) did not differ significantly.

Interpreting the main effects, it is apparent that high seed moisture percent prior to drying reduced germination in a generally linear manner, Table 4. At the 27.1% harvest moisture, germination was 96.8%, at 33.8%, 91.6% and at 41.2% the germination dropped to 84.2%. A similar pattern of decreased germination is detected for the influence of temperature: as temperature increases, percent germination decreases. At a drying temperature of 110°F, germination over all other factors was 95%, at 120°F, 92.5% and at 130°F percent germination was 84.2%. The effect of temperature is however, not linear; the reduction in germination as temperature is increased from 110°F to 120°F is small as compared to the rather big reduction in percent germination as temperature is increased from 120°F to 130°F, Table 3.

The significance of sampling level may be explained in terms of a temperature differential between the lower level, which was near the heat source, thus warmer, and the upper level which was further from the heat source, thus cooler. The pattern of variation in germination with reppect to sampling levels fits the response pattern discussed above for temperatures.

To interpret the significant interactions it is necessary to

Table 3. The relation between drying temperature and germination of seed corn, both aged and unaged.

Drying temperature °F	Percent germination	
	Unaged seed	Aged seed
110	95.9	86.8
120	92.5	85.0
130	84.2	79.2

Table 4. The relation between moisture of seed corn at harvest and germination of seed corn, both aged and unaged.

Moisture at harvest %	Percent germination	
	Unaged seed	Aged seed
41.2	84.2	76.4
33.8	9.16	83.3
27.1	96.8	9.13

Table 5. The relation between sampling level and germination of seed corn, both aged and unaged.

Sampling level	Percent germination	
	Unaged seed	Aged seed
Upper level	95.2	89.0
Lower level	86.2	78.3

Table 6. The relation between height of grain in column and germination of seed corn, both aged and unaged.

Height of grain in column	Percent germination	
	Unaged seed	Aged seed
48 inches	91.6	85.0
60 inches	90.1	82.4

consider specific groups of treatment means, Table 7. In all cases, simple interactions involving moisture are significant. Moisture interacts with temperature, height of grain in column, (although the main effect of height of grain in column is non-significant) and sampling level.

Considering moisture x temperature interactions, the significance can be explained by the high germination of samples harvested at 27.1% moisture and dried at 110°F and 120°F. These treatments are not significantly different, whereas, percent germination due to all temperatures within either 33.8% moisture or 11.3% moisture are significantly different. Apparently, when moisture is as low as 27.1%, temperatures ranging from 110°F to 120°F did not influence germination (Figure 1).

A drying temperature of 110°F at 33.8% moisture produced as good a germination as either 110°F or 120°F at 27.1% harvest moisture. Thus, it is readily seen that the higher the harvest moisture the less the ability of the corn to withstand high drying temperatures. Corn harvested at 27.1% moisture withstood 110°F drying temperatures with no apparent reduction in viability but germination is appreciably lowered at 130°F. At 33.8% moisture, it could withstand 110°F drying temperature, but germination is significantly lowered when dried at both 120°F and 130°F. At 41.2% moisture, even 110°F significantly lowers germination.