GRAIN DAMAGE STUDIES IN MODIFIED CROSSFLOW DRYERS

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ABSTRACT

GRAIN DAMAGE STUDIES IN MODIFIED CROSSFLOW DRYERS

By

Adalberto Diaz

The effect of the operator on testing the breakage, stress-cracks and germination of shelled corn was analyzed. The dependability of the quality tests when performed by different operators was assessed.

The Stein Corn Breakage test, candling (stress-crack test) and the standard germination test as well as test weight were used as quality criteria.

Tests of grain damage at six locations along the Michigan State University dryer were performed using seed corn. Corn obtained through trade channels was used for the other tests.

The two modified crossflow dryers, the Hart-Carter moving bed model and the Michigan State University stationary bed type, were investigated. Better uniformity of grain moisture and improved quality after drying are the main differences of these dryers as compared to conventional crossflow dryers. The effect of the two dryers on corn quality was investigated in particular.

Statistical analyses showed the significance of the operator effect on stress-crack results obtained by the method of candling. No significant difference was observed in breakage method, germination test, test weight

and moisture content determination.

Comparing the Hart-Carter (HC) dryer with the Michigan State University (MSU) dryer with respect to the number of stress-cracks, a significant difference between dryers was observed. Breakage was not significantly different.

Checked kernels (seed corn) along the sections of the MSU dryer were affected by the drying treatment. High temperature grain exposed to rapid cooling did not increase the number of stress-cracks as expected. Breakage and germination, however, were significantly affected.

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GRAIN DAMAGE STUDIES
IN MODIFIED CROSSFLOW DRYERS

By

Adalberto Diaz

A DISSERTATION

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Michigan State University
in partial fulfillment of the requirements
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I dedicate this work to my parents, to my wife, Mireya, and my children, Enrique and Barbara.

and

Dr.

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ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

The diversified uses of corn have motivated extensive research on grain quality.

The high initial moisture of shelled corn in the field requires the application of artificial drying to prevent corn deterioration. Depending on air drying temperatures, different degrees of damage to the grain quality will occur.

High air drying temperatures impair the grain quality by increasing the stress-cracks and the breakage and by decreasing the germination. Millability is also affected by the lower quality giving lower yields in the dry and wet milling processes.

Drying conditions like air temperature, and humidity as well as air flow, will affect corn quality to a different extent depending on the drying method used.

Continuous drying methods have been modified in order to achieve the lowest amount of damage using heated air. Energy consumption is also being optimized in continuous dryers taking into account the quality of the grain. Furthermore, processing (milling) of damaged corn requires more energy to produce the same amount of final product.

The purposes of this study were:

a) To analyze the operator effect on grain quality tests (breakage, stress-crack, germination, test weight and moisture content determination)

b) To compare two modified cross flow dryers (The Hart-Carter and the Michigan State University) from the standpoint of grain damage

c) To investigate seed corn damage at different locations along the Michigan State University crossflow dryer.

CHAPTER II

REVIEW OF LITERATURE

Importance of Corn Losses.

The world production of corn is used as food for man and domestic animals, and for the manufacture of protein, oil and other materials. Potable alcohol is also manufactured from corn.

Developing countries, mainly, use their corn production for food without previous industrial processing. It represents the principal source of food for the population. Thus, these countries are affected by losses of corn in quantity and quality caused in different ways with storage being a principal factor.

Officials of the Food and Agriculture Organization (FAO) of the United Nations have estimated that 5% of all harvested grains are lost before consumption (Christensen and Kaufman, 1968). In 1966, the world production of corn was about 8,500,000,000 bushels and if the 5% loss factor is applied, 425,000,000 bushels were lost. Drying is only considered as an aid to maintain quality of stored grains and seeds.

Losses can occur when heated air causes damage to the grain. Uhrig (1968) defined damaged grain as: "grain that lacks certain characteristics of quality grain."

Meaning and Parameters to Evaluate Corn Quality.

To describe the quality of grain, Official Grading Standards (Table 2-1) have been defined. Akiyama (1972) presented a study of corn damage and its effect on official grading standards. He considered the test weight, moisture content, heat damage, broken corn and foreign material as corn quality factors.

Corn grain quality is a term possessing various meanings for different grain users or handlers. To farmers, quality relates to maturity, appearance and test weight. The seedsman may relate quality to germination, uniformity, and good seedling emergence. The miller relates quality as yield of desired product. An exporter may seek test weight and low moisture, foreign matter and total damage as quality factors. Finally, a livestock feeder may look at corn protein quality and total digestible nutrients (Duncan et al., 1972).

Requirements of Artificial Drying.

Quality of grain dried with heated air is often lower than that dried naturally (Sinha and Muir, 1973).

Due to high moisture content of the corn grain at the time it is harvested, it has to be dried before it can be stored for any length of time. Short harvest seasons and large acreages harvested, require a speed up of the drying

U.S. GRADE AND GRADE REQUIREMENTS FOR CORN.

Grade	Minimum test weight per bushel	Maximum Limits of --			
		Moisture	Broken corn and foreign material	Damaged Kernels	
				Total	Heat-damaged kernels
	Pounds	Percent	Percent	Percent	Percent
U.S.No.1	56.0	14.0	2.0	3.0	0.1
U.S.No.2	54.0	15.5	3.0	5.0	0.2
U.S.No.3	52.0	17.5	4.0	7.0	0.5
U.S.No.4	49.0	20.0	5.0	10.0	1.0
U.S.No.5	46.0	23.0	7.0	15.0	3.0
U.S. Sample grade	U.S. Sample grade shall be corn which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; or which contains stones; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.				

Table 2-1. Grade and grade requirements for corn.

process (Thompson, 1967). Accelerating the drying process results in an increase in drying capacity but it is obtained by increasing the drying air temperature, thereby affecting the quality of the dried corn.

Storage losses caused by insect damage, mold, and heating due to excess moisture can be practically eliminated by drying and aeration (Hall,1957). Evidently, modern techniques of harvesting corn have made necessary the use of heated air.

Several methods of drying have been evaluated by comparing the influence of heated air and its effect on corn quality. Thompson (1967) evaluated three continuous-flow dryers: the cross-flow, concurrent flow and counter flow dryers. He determined the corn quality after drying from each dryer. He concluded that concurrent flow produces grain of higher quality for marketing than either of the other two methods operating under the same drying conditions. Bakker et al., (1972) compared grain dried with a concurrent flow dryer and counter flow cooling with grain dried in a crossflow dryer and found that the foreign matter and germination percentages with the concurrent-counter flow dryer design were better than with commercial type dryers. Converse (1972) described a new dryer design called "A Commercial Crossflow-Counterflow Grain Dryer: The Hart-Carter" model.

Corn Quality Parameters Considered In Corn Artificially Dried.

Generally, those tests used to evaluate corn quality or grain damage have been breakage, stress cracks, germinability, discoloration, humidex index and millability. An evaluation of grain damage with respect to breakage, stress cracks, humidex index and millability was made by Thompson (1967), and breakage and germination by Bakker (1972). Thompson and Foster (1963) also studied stress cracks and breakage in artificially dried corn.

For measuring one parameter different laboratory procedures may exist. Kamimski (1968) studied the need for standards for evaluation of grain damage and found that the information obtained with some of these different methods showed generally poor correlation between the results. This implies that a breakage test, for instance, must be performed in a specific manner which is adequately defined. The causes of broken kernels, stress cracks, loss of germination, and quality of the corn grain for milling by heated air drying is explained below.

Breakage.

Corn dried artificially becomes brittle and this leads to breakage of the grain during handling (Sinha and Muir, 1973). Keller et al. (1972), also, mention that field shelling and artificial drying make corn kernels more susceptible to breakage. Sinha and Muir (1973) concluded that it is sometimes difficult to distinguish between damage caused by harvesting and drying. Improperly dried corn tends to become brittle and breaks readily with further loading, unloading or shipping increasing the amount of grain breakage (Kamimski, 1968). Bilanski (1972) studied damage resistance of seed grains and found that corn kernels were weakest when impacted on their edge side and strongest when impacted on their flat side.

Mechanical strength or resistance to breakage of grains varies with moisture content, variety, temperature, type of load, and orientation of the kernel with respect to the direction of load (McGinty and Kline, 1972).

Thompson and Foster (1963) found that corn dried with heated air (140° to 240°) was two or three times more susceptible to breakage. The initial moisture content also affected the susceptibility of the grain to break. Corn dried from 30 percent initial moisture was more susceptible to breakage than corn dried from 20 percent. The same results were found by McGinty and Kline (1972), when they compared the Cargill Grain Breakage and the Stein Breakage testers. Susceptibility to breakage increased when drying air temperature and air flow rate increase. When drying air temperature was increased from 140°F to 240°F, breakage increased from 16.5% to 19.3%, respectively. Breakage was increased from 15.8% to 16.4% with an increase from 32 to 62 cfm per bushel (Thompson and Foster, 1963).

Thompson (1967) presented results of the effect of temperature on quality where breakage (Stein Breakage tester) was 4.3 percent more at 200°F than at 300°F. Breakage is related to the number of stress cracks in the kernel. Thompson and Foster (1963) showed this relationship in terms of increase in breakage due to drying; the percentage of checked kernels (6 to 54%) increased breakage from 8 to 20%.

Sinha and Muir (1973) using two-stage dryeration found a slight increase in the number of kernels without stress cracks, but no reduction in breakage. Tests conducted with partial heat drying resulted in an increase of sound kernels and a considerable decrease in the amount of breakage.

Besides, the brittleness of the grain after drying can make the grain fall apart at the first impact; this produces a higher percent of breakage (Roberts, 1972).

Improper methods of drying can cause more damage to the grain (internally fractured kernels) and Bailey (1968) classified these as using too high a drying temperature, drying too far in one pass, holding corn in heated air too long, drying down too far, or cooling too quickly. Thompson (1967) compared the effect of counterflow and delayed cooling and found that a concurrent flow dryer with a counterflow cooler is not an adequate substitute for delayed cooling for reducing the brittleness of dried corn. He, also, concluded that drying speed, expressed in terms of moisture loss in percentage points per hour, increases the brittleness; higher breakage is the result.

Sinha and Muir (1973) have presented a table (Table 2-2) of comparison between drying methods with heated air. Partial heat drying gives less breakage and a higher percentage of sound kernels. However, partial drying has the disadvantage that a long period of drying is required before a safe moisture level is reached.

Drying Method	Initial Moisture %	Sound Kernels (without stress cracks) %	Breakage %
Conventional Continuous Flow	25	8.8	11.3
Dryeration	25	60.6	6.7
Two-Stage Dryeration	25	72.0	7.0
Partial Heat Drying	26	80.4	4.5
Unheated Air	26	93.8	2.0

Table 2-2. Effect of drying method on brittleness of dried corn according to Sinha and Muir (1973).

Stress Cracks.

Stress cracks are fissures in the corn endosperm not on the seed coat. Stress cracks have been mentioned before as causing susceptibility to breakage. It also influences germination and millability. Thompson and Foster (1963) found that there is some relationship between stress cracks and germination, and checked kernels almost assures low germination. However, the absence of stress cracks does not assure high viability.

The severity of the drying treatment is indicated by the number and type of stress cracks (Thompson and Foster, 1963). Rapid drying or cooling, or both, are responsible for stress cracks (Thompson, 1967). Ross et al. (1971) studied stress cracking of white corn as affected by over-drying and found that stress cracking was most severe in the grain dried to 10 or 14 percent moisture content, in the drying air temperature range of 130°F to 220°F. Samples dried with air at 100°F had a noticeable drop in stress cracking. Stress cracking decreases with lower final moisture contents and as drying was started at lower initial moisture contents. This phenomenon has not fully been explained; the authors explain that physical and chemical changes occur during overdrying that make the grain more resistant to stress cracking during the cooling period.

Sinha and Muir (1973) mentioned the same factors affecting stress cracking such as: rapid drying, increasing of drying temperature, moisture content before and after drying, rapid cooling. Thompson (1967), using the candling method to detect stress cracks, investigated the effect of temperature, initial moisture and airflow rate on quality and obtained the following results:

Table 2-3. Percentage of checked kernels at various different drying conditions (Thompson, 1967).

	Drying Air Temp.				Initial Moisture				Air Flow Rate		
					23		18				
	Cont.	200	300	400	I	F	I	F	Cont.	Low	High
Checked Kernels %	6.8	45.3	39.0	27.8	6.8	36.8	3.2	39.1	6.8	37.8	36.8

I = initial percentage of checked kernels before drying.

F = final percentage of checked kernels after drying.

Corn dried at excessive temperatures develop cracks and fissures in the endosperm that will not yield large grits as is required in the milling industry (Watson, 1960). Checked kernels increase from 20.2 to 40.2% when the drying air termperature is raised from 140°F to 290°F (Thompson and Foster, 1963). They, also, found a 64.9 percentage of multiple cracks, using candling to detect cracks, in corn dried at 140°F. At 290°F, multiple cracks decreased but checked increased.

Germination and Viability.

Germination and viability are very important corn quality parameters for the dry and wet milling industry. Few results and tests used in determining germination and viability are available. Viability is determined by the

2, 3, 5, triphenyl tetrazolium chloride test.

Germination.

When heated air is employed for drying corn, loss of germinability is directly related to high grain temperatures (above 110°F).

Temperatures above 140°F decrease germination as mentioned by Watson (1960), Hall (1957) and Christensen et al. (1969). However, Bakker et al. (1972) using a concurrent flow dryer with counter flow cooling, found that air temperature at 220°F lowered the germination percentage (standard germination test) by less than ten points which is lower than usually obtained in commercial crossflow dryers.

Watson (1960) presented germination data of two experiments, where germination percentage was adversely affected by drying temperature at high air flow rate, by high relative humidity and by high initial grain moisture; at 32 percent initial moisture, and 120°F air temperature, 40 and 15 percent relative humidities of the drying air, the resulting germination was 39 and 75 percent, respectively. At 21 percent initial moisture, using the same temperature and relative humidities of drying air, germination was 94 and 95 percent, respectively. Under the same experiment when temperature of the air was increased the germination percentage decreased drastically.

Another source of loss of germination is the physical damage caused to the grain. As drying stresses increase, single cracks develop into multiple cracks or checks assuring low germination (Thompson and Foster, 1963). Brekke et al. (1972) published results of the effect of drying air temperature (Table 2-4).

Table 2-4. Germination of corn artificially dried at various temperatures.

Drying Air Temp.	Approx. Maximum Kernel Temp.	Dried Corn Moisture	Drying Time	Germination
35-90	60	15.8	48	85
90	90	16.0	7	75
140	135	17.4	2.5	23
190	180	16.6	1.2	6

Viability.

Mayer and Poljakoff-Mayber (1963), Sinha and Muir (1973) and Roberts (1972) consider viability as the ability of seed to germinate.

Mayer and Poljakoff-Mayber (1963) have concluded that "even if a seed loses its viability this does not imply that all metabolic processes stop or that all enzymes are inactivated. Only the sum total of processes which lead to germination no longer operates." Positive results of viability obtained with the 2, 3, 5, triphenyl tetrazolium chloride method do no indicate a 100 percent of germination (Mayer and Poljakoff-Mayber, 1963).

Watson (1960) considers that grain dried at a temperature above 150°F shows loss of viability. However, he reports that loss of germination is not a good index of milling damage.

Millability.

Physical and chemical changes in corn kernels occur when it is dried with heated air.

Excessive drying temperatures reduce yields of starch and results in lower oil yields when wet milled; this, also, increases brittleness of corn, reduces the nutritional value and the germination decreases (French et al., 1964).

Drying corn at temperatures above 140°F lowers the fermentable carbohydrate content and reduces the efficiency of separation of starch in wet milling (Roberts, 1972). Sinha and Muir (1973) have concluded that corn used in the wet milling process should not be heated above 140°F to 149°F.

Watson (1960) stated that the use of overheated corn results in lower yield of starch and higher protein content in starch, because the protein matrix holding the starch in endosperm cells will not soften in the steeping process and will not release starch during milling. Cracks will cause excessive breakage during dry milling thereby reducing the yield of large grits. Protein content, the viscosity of its aqueous pastes and the color of refined corn syrup are important criteria of starch quality.

Preservation of corn viability is another indicator of acceptability for milling. Watson (1960) considers the viability of corn kernels to be destroyed when corn is heated above 140°F.

Lobanov (1964) says that under modern food technology, the germination capacity of food grain (corn) is extremely important and that so-called dead grain gives products of lower quality because its capacity for fermentation is less than that of grain with a high germination capacity.

Reduction in germinability from drying at high temperatures occurs at about the same temperature that results in the chemical changes that make difficult the separation of starch and protein (Christensen and Kaufman, 1969).

Concurrent flow drying test made by Thompson (1967) in 1964 showed that the millability score, analyzed by the prime starch milling test, decreased as the temperature increased. Drying air temperature of 200°F, 300°F, and 400°F gave a millability score of 88.8 percent, 73.4 percent, and 54.3 percent, respectively. In 1965, he obtained the same results with an increase of 5 to 10 points in millability scores. Thompson (1967), also, evaluated the effect of the air flow rate on the millability score which decreases at high flow rate. The effect of the depth of the drying column (2 and 4 feet) did not affect the millability scores. Initial moisture of the grain of 23 and 18 percent decreased millability from 91.7 to 69.4 percent and from 89.4 to 86.7, respectively.

CHAPTER III

EXPERIMENTAL PROCEDURES

Corn Grain Quality Parameters and Drying Method.

Breakage, stress crack and germination were chosen as parameters to evaluate grain damage and to determine corn quality, using high-temperature air. Cross-flow drying, one of the methods of continuous drying, was used to dry the grain.

Methods of Corn Grain Quality Evaluation Used.

Although several methods exist for each test, there has been little work done on comparing criteria for choosing the breakage and stress crack tests.

The stress crack detection method of candling offers the possibility of obtaining a correlation between the kind of stress cracks and germination. Besides, the equipment is easy to build in the laboratory, is inexpensive and is precise in determining stress cracks. Thompson and Foster (1963) compared candling and x-rays, and reported that candling was a better method to distinguish cracks.

For the breakage test, a Stein Grain Breakage tester[1]

[1] Model CK2, Fred Stein Laboratories, Atchison, Kansas.

was used. It was selected on the basis of McGinty's (1970) report which considers this device as simpler in design, easier to operate and presenting a steep breakage-tendency curve that gives good readability, when compared with other breakage test devices.

Corn Samples.

Three different lots of corn samples were analyzed, U.S. No. 2 corn from a Mason elevator, Hart Carter (HC) samples from Minnesota and certified seed corn (SC).

Table 3-1. Percentage of moisture content of the Hart Carter samples received.

Moisture Content	Sample Number						
	121-HC	122-HC	123-HC	124-HC	125-HC	126-HC	127-HC
Undried Samples	25.0	25.0	25.0	25.0	23.5	23.5	23.5
Dried[1] Samples	20.0	16.0	14.5	20.0	15.0	15.0	14.8

Conditioning of Corn Samples.

The U.S. No. 2 corn, the Hart Carter and the seed corn samples were conditioned in a conditioner, to reach the equilibrium moisture content (12.5%) at 80°F and 75 percent relative humidity before the tests (breakage, stress-crack and germination) were performed.

[1] Corn samples dried in the commercial type.

Twelve samples of U.S. No. 2 corn, distributed at random among three operators, were tested. Each operator analyzed at the same time one complete set of tests.

The Hart Carter samples (123-HC, 126-HC and 127-HC) were analyzed by one operator. Due to the limited availability of wet corn, only 123-HC, 126-HC and 127-HC could be compared to 123, 126, 127-MSU dried samples.

Seed corn samples (123-SC, 126-SC and 127-SC) were rewetted to 25 percent moisture, and kept for 5 days in a 40°F box before drying. These samples were dried in the MSU dryer.

<u>The Grain Conditioner.</u>

All dried samples were placed in a conditioner (Figure 1) before performing the tests. The conditioner was set up in such way it provided a moisture content equilibrium of 11 - 12.5 percent. Saturated sodium chloride solution conditioned the air humidity to 75 percent inside of the conditioner and the temperature was controlled by placing the conditioner in a 80°F box.

A small fan maintained the air circulation in the conditioner at all times. To dissipate the heat coming from the fan motor an air conditioning was turned on periodically. However, the temperature was not critical since the sodium chloride provides the same equilibrium moisture for a wide range of temperature (32 - 122°F).

The samples were taken from the grain conditioner after

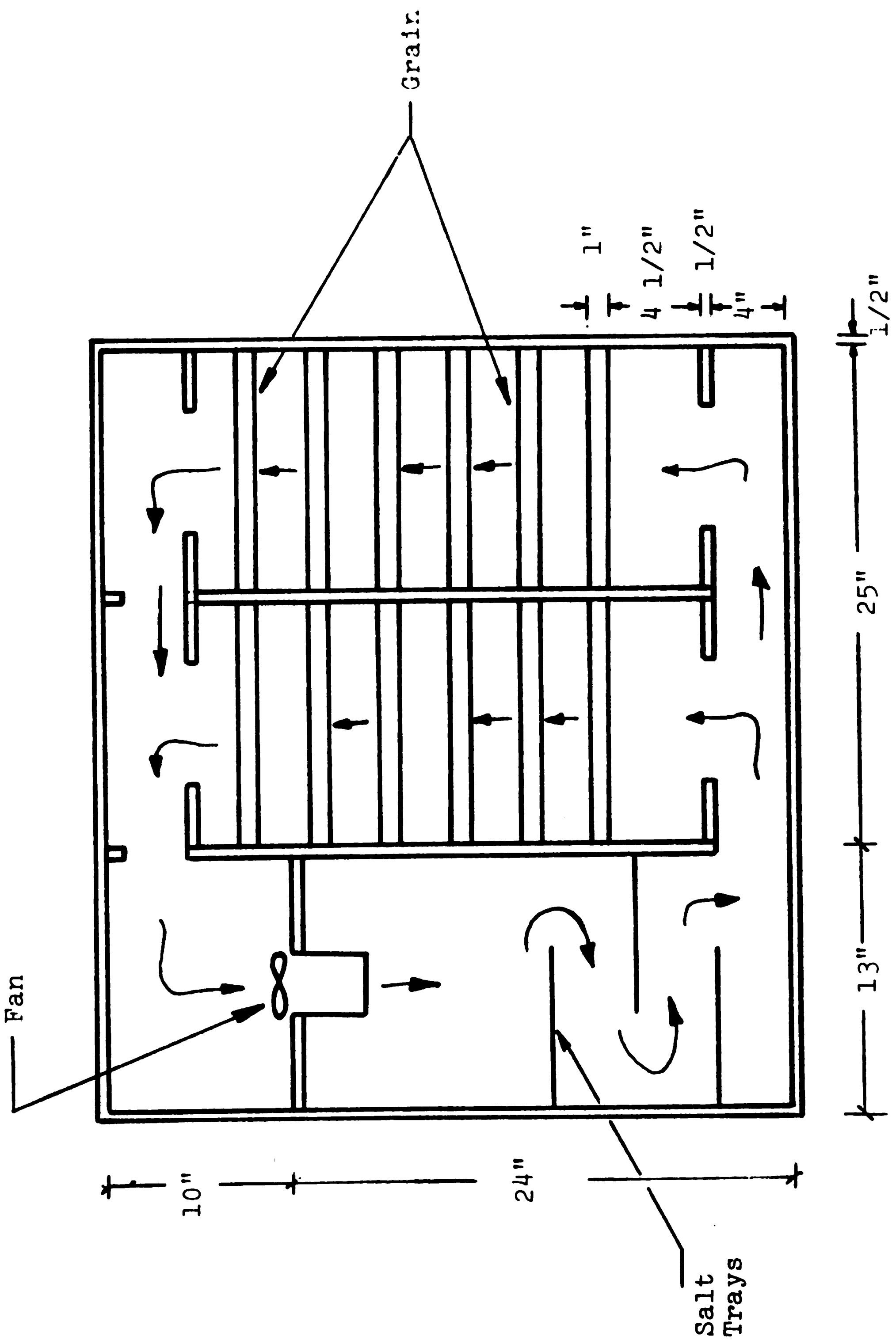

Figure 1. Schematic of conditioner.

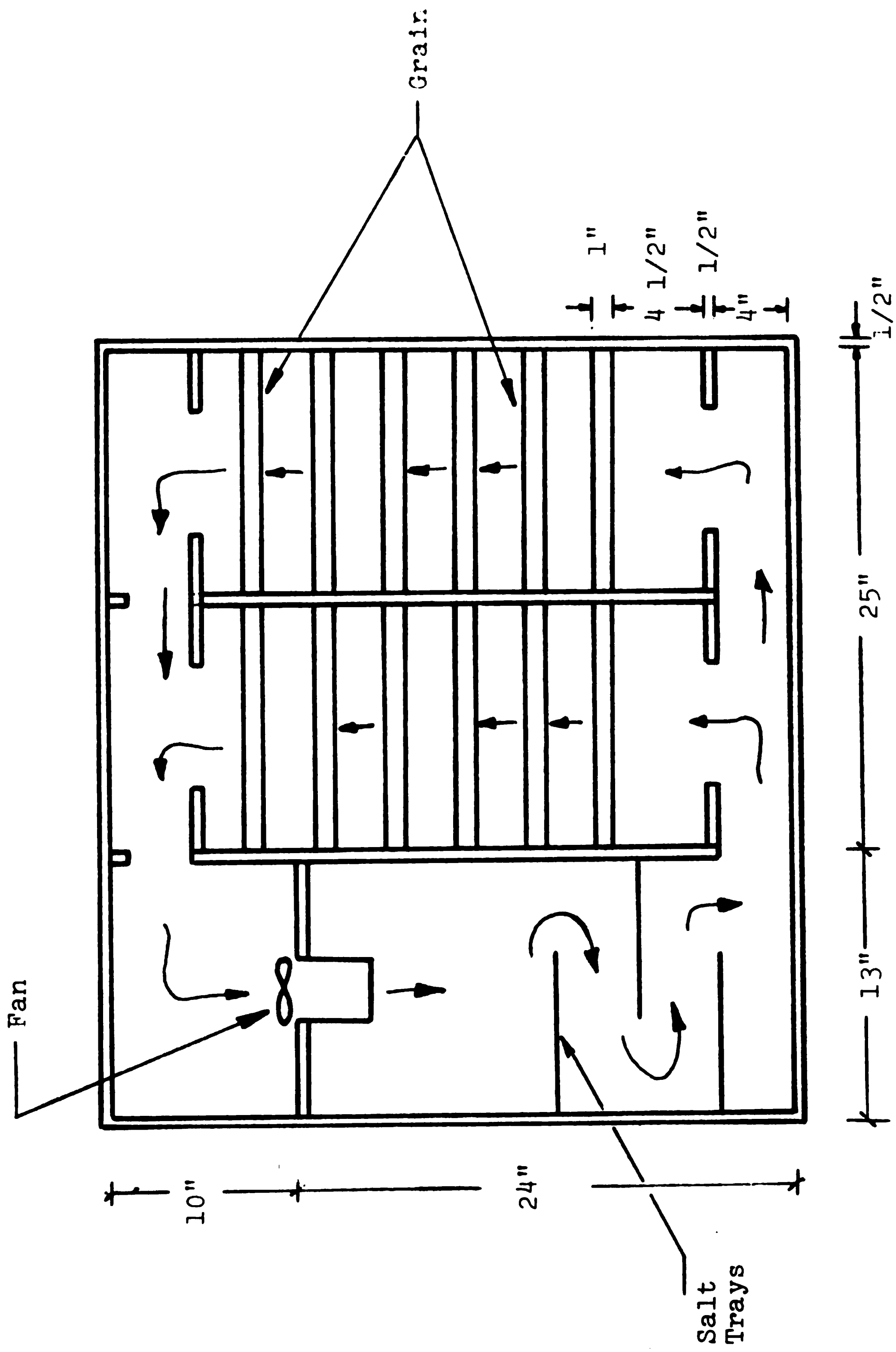

Figure 1. Schematic of conditioner.

4 or 5 days and the moisture content of the samples was determined.

Breakage Test Procedure.

Broken and cracked kernels and foreign material were removed from 200 grams conditioned grain.

Then a sample of 100 grams was placed in the Stein Corn Breakage tester; when the machine started, the impeller at a speed of 1725 RPM, threw the kernels against the sides of the container for two minutes. The time that the sample remained in the breakage machine was controlled by a timer, insuring all samples to be exposed to the same treatment.

Following the two-minute time period, all of the sample was poured into a 12/64" round hole sieve. The remainder on top of the sieve was weighed and subtracted from 100 grams. The result yielded the percentage of breakage.

Stress Crack Test Procedure.

The candling device (Figure 2) for determining stress cracks, consists of a rectangular wood box with a 150-watt incandescent bulb in the middle of the box. The top is covered with glass painted a red color everywhere except for a little square where the kernels are placed to be examined.

At the same time that the breakage sample was taken, a separate sample of about 75 grams was taken, and the cracked and broken kernels as well as foreign materials were

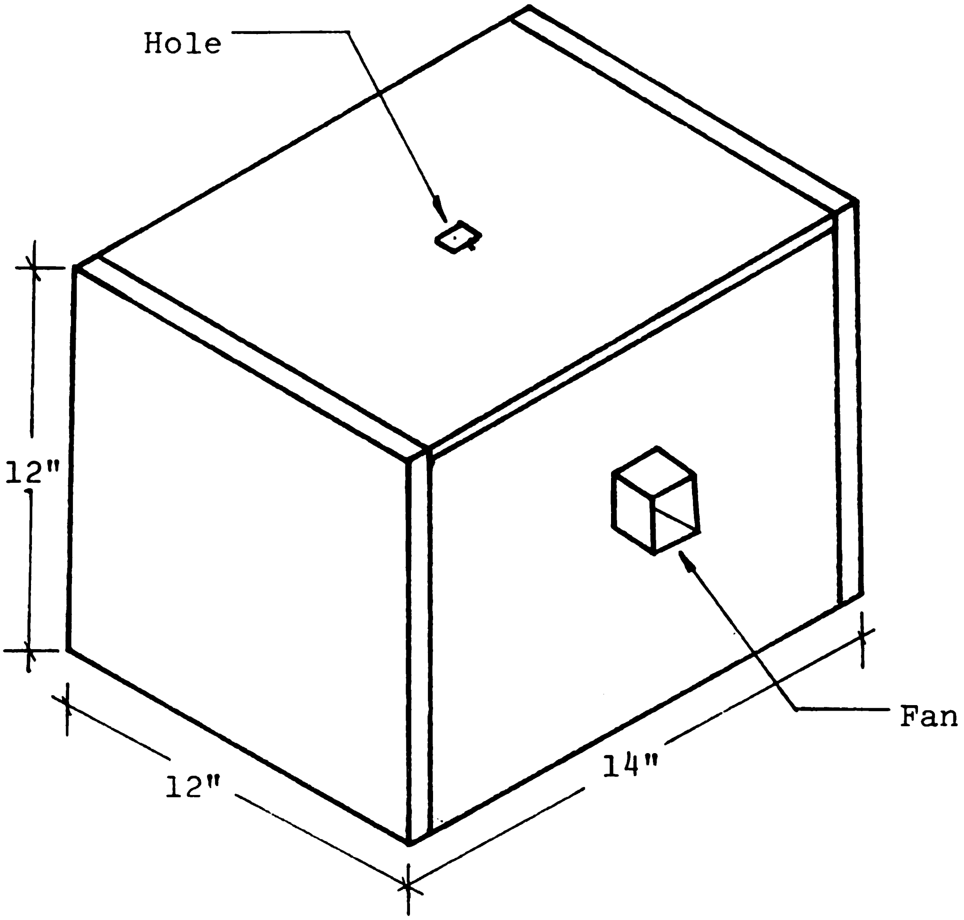

Figure 2. Wood box to evaluate stress-cracks by the candling method.

removed. Kernels having a chalky appearance had to be taken out of the samples because of the difficulty in looking through them.

Then, from the remaining kernels of the cleaned sample, a 50-gram weight was stored in a plastic bag until analysis.

Four different categories of kernels were considered: sound kernels, single cracks, multiple cracks and checked kernels. Single crack are those kernels having just one crack. Multiple cracks are those presenting two or more cracks. Checked kernels have horizontal and vertical cracks given the appearance of a sieve configuration of fissures.

Each kernel of the 50-gram sample was examined through the light. The kernel was placed in different positions, in order to detect all cracks through the kernel.

Then, sound kernels, single crack, multiple cracks and checked kernels were counted and reduced to percents.

The number of corn kernels in 50-gram samples varied from 155 to 180, depending on the kind of grain.

Germination Test.

Samples of 100 kernels were wrapped up in wax and brown towel paper. The brown towel sheets enclosing the kernels were moistened and wrapped with wax paper to keep the towels moist.

Garbage cans placed in a 80°F box kept the samples for the seven-day period recommended by the Association of

Official Seed Analysts. A first count and moisture control were made at the fourth day of the test. When the required period of time had elapsed, the germinated seeds were counted and the percent of germination determined.

Test Weight and Moisture Content Determination.

Test Weight.

To obtain the test weight two procedures had to be used. The conventional method used a one-quarter cup. It could be employed if the size of the sample was sufficient to fill up the cup.

For small size samples, which was the case of the samples taken from the six sections of the MSU-dryer samples (500 grams or less), a 250-ml. beaker replaced the one-quarter cup. It was filled up with corn and weighed. The weight results were correlated to a previously performed linear regression analysis equation,

$$Y = A_o + A_1X$$

Table 3-2 gives the linear regression analysis results.

Moisture Content.

Moisture content was determined in the Steinlite[1] tester. The corn sample of 100 grams is placed into a grain chamber, from where it is dropped into a chamber formed by two plates of a condenser.

[1] Fred Stein Laboratories, Atchison, Kansas.

Table 3-2. Equivalence of pounds per bushel for gram weights.

WEIGHTS	
lbs/bu	grams
47.00	154.689
47.25	155.783
47.50	156.877
47.75	157.971
48.00	159.065
48.25	160.159
48.50	161.253
48.75	162.347
49.00	163.441
49.25	164.535
49.50	165.629
49.75	166.724
50.00	167.818
50.25	168.912
50.50	170.006
50.75	171.100
51.00	172.194
51.25	173.288
51.50	174.382
51.75	175.476
52.00	176.570
52.25	177.664
52.50	178.758
52.75	179.852
53.00	180.946
53.25	182.040
53.50	183.134
53.75	184.228
54.00	185.322
54.25	186.416
54.50	187.511
54.75	188.605
55.00	189.699
55.25	190.793
55.50	191.887
55.75	192.981
56.00	194.075

The dielectric properties of the grain are based on the moisture content. A certain capacitance value corresponds to a certain moisture content.

In order to check the results of the Steinlite, the air oven method, using the air-oven (212°F for 72 hours), was used. A sample size of 100 grams was placed on a screen tray inside the oven and weighed after the required time.

The Dryer.

The Commercial Type.

The commercial type is a continuous cross flow dryer which has been modified to improve some characteristics of the conventional cross flow dryer. The modified design gives a better moisture content distribution in the grain. It consists of three sections; the first and the second to dry, and the third to cool the grain (Figure 3).

The exhaust air in the first section is exhausted to the atmosphere. The outlet air of the second and third sections is recirculated. This design requires less energy than non-recirculating models.

Laboratory Type.

A steel dryer consisting of one static section of the commercial type was built in the Agricultural Engineering Department at Michigan State University (MSU dryer). Two drying stages and one cooling stage could be accomplished by switching the one section (Figure 4). Heated air is

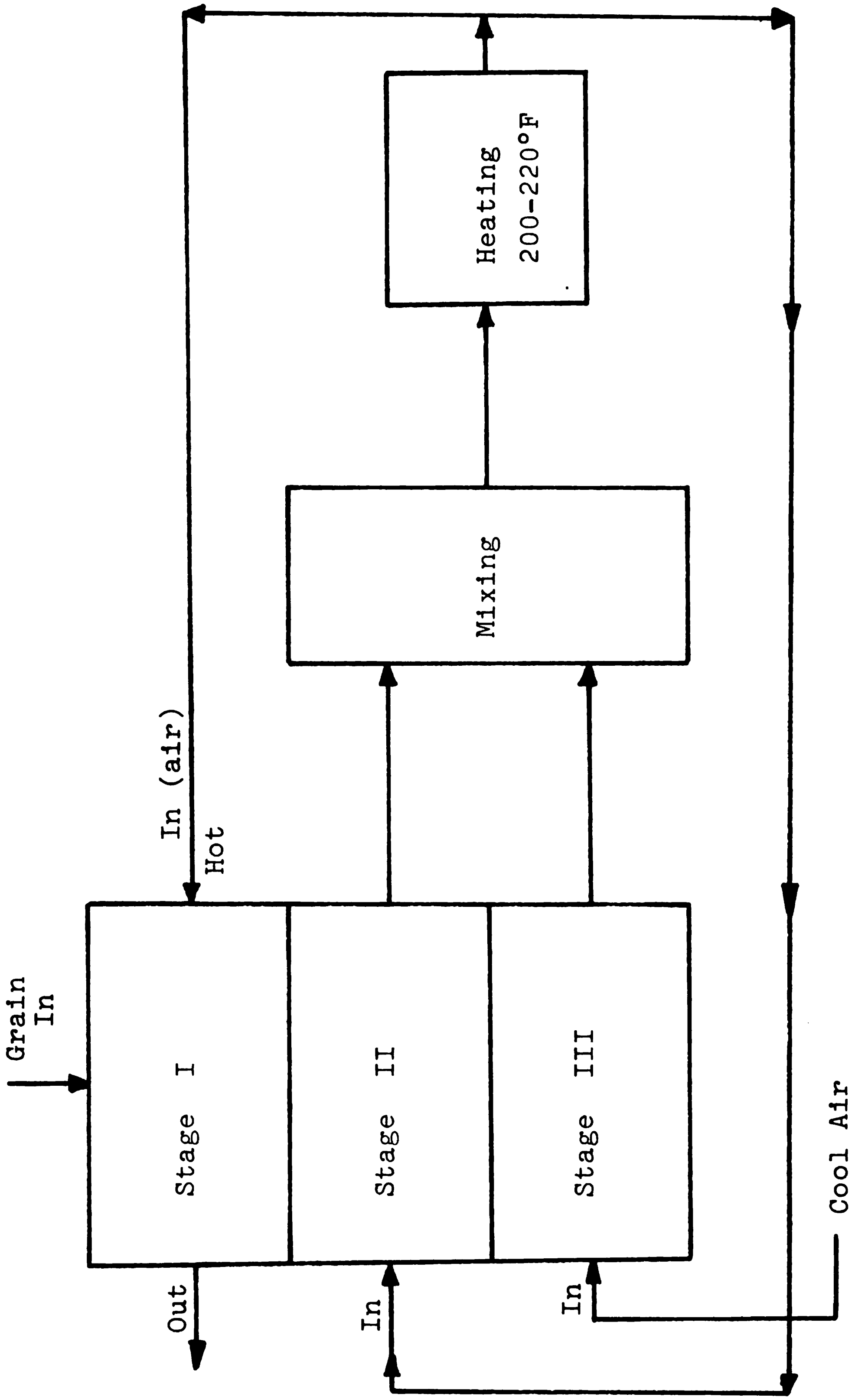

Figure 3. Diagram of the Hart-Carter crossflow dryer.

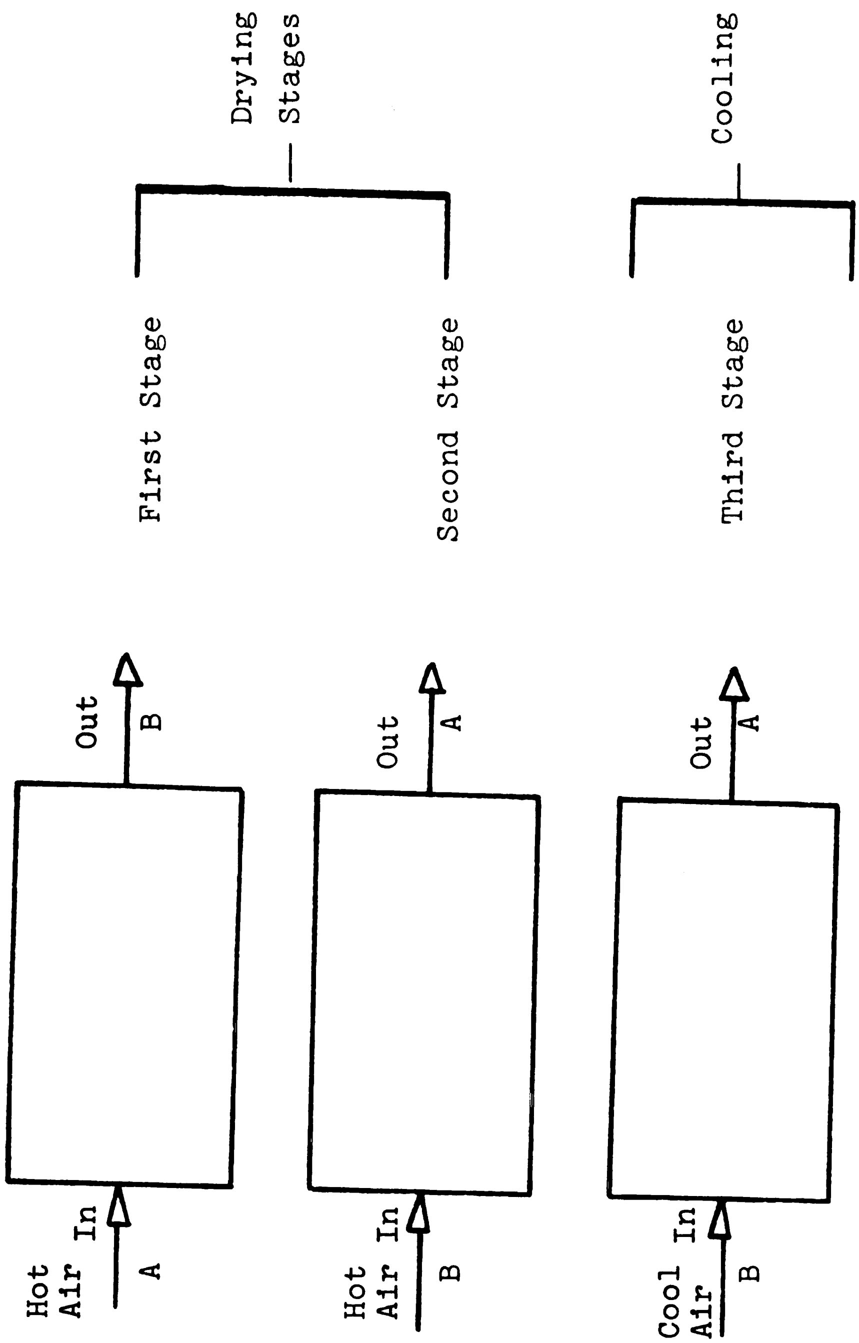

Figure 4. Diagram of the different stages of the MSU dryer.

blown first at one side (A) of the grain layer for a time period equal to the residence time of the grain within the first stage. The heated air is then blown through the other side (B) of the grain layer for a time equal to the residence time of the second stage. Second stage is very important, since in that phase non-uniformity of moisture content of the dried grain is avoided. In the conventional cross flow type, one side of the grain column is exposed to heated air. With the Hart-Carter modification, both sides are exposed to heated air. Cooled air is then blown through the same B side for a time period equal to the residence time in the third (cooling) section of the continuous flow dryer.

The MSU dryer is shown in Figure 5. It has six sections of 2 inches each, giving a column width of corn of one foot. It also has two more inches in the upper part to compensate for up to 30 percent shrinkage.

The upper part is removable to facilitate filling and emptying of the dryer. The grain temperatures through the MSU dryer can be continuously monitored by copper-constant-an thermocouples placed in each section. Relative humidity can be monitored by hygro-sensors.

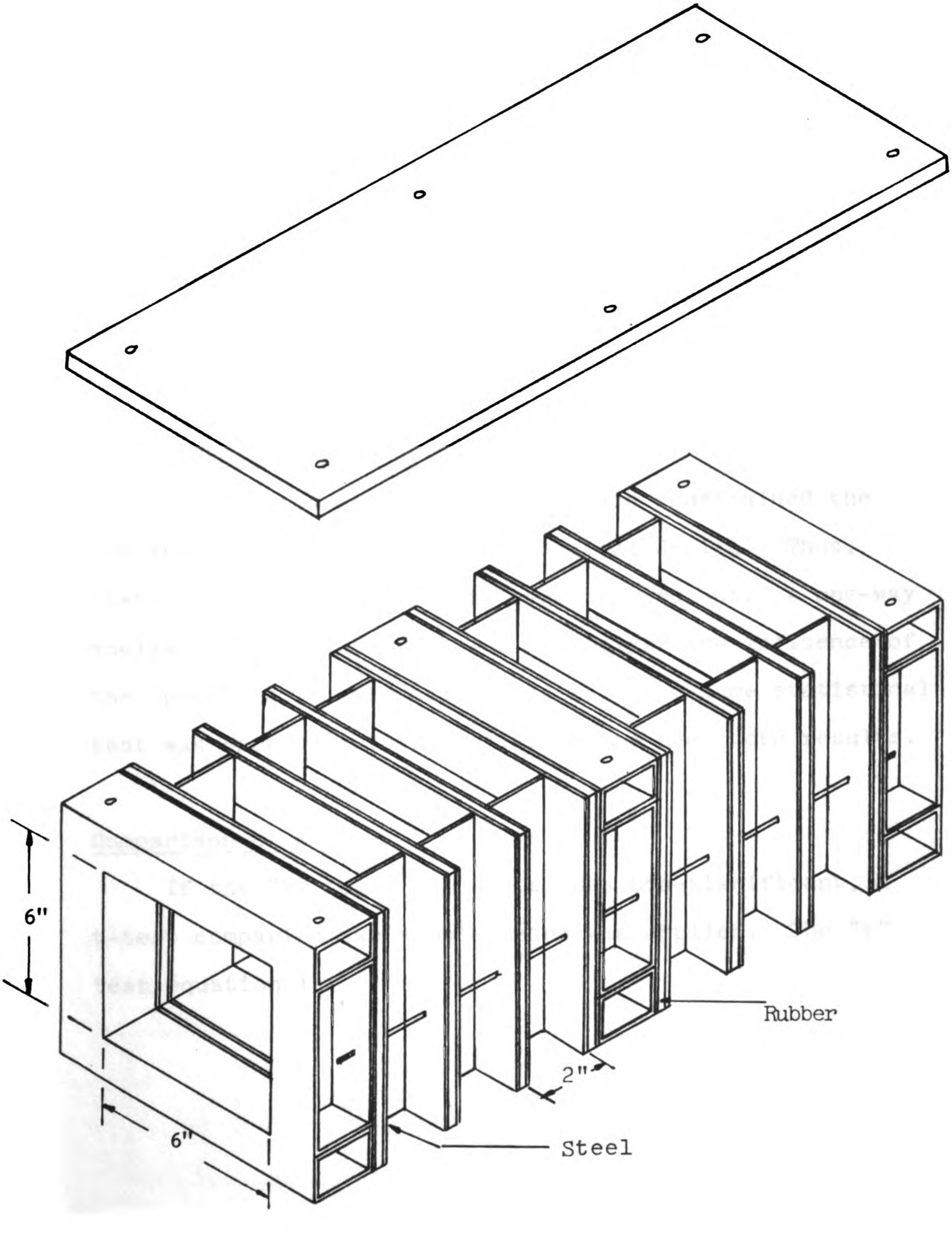

Figure 5. The stationary bed MSU dryer.

Drying Conditions.

Humidity and Temperature of the Air.

In order to condition the humidity of the air, an Aminco-Aire[1] unit was used. An electric heater was used to raise the air temperature up to 240°F. Air flow was measured continuously by a laminar flow meter[2].

The arrangement of these parts and of the dryer is given in Figure 6.

Statistical Analysis of the Data.

The limited availability of grain constrained the possibility of an a-priori statistical design. Thus, posteriori statistical tests were carried out. A one-way analysis of variance was used to analyze the influence of the operators in corn quality tests. The same statistical test was carried out for analyzing the seed corn results.

Comparison of Means.

If the "F" value calculated was non-significant, a t-test comparing two sample means was applied. The "t" test equation is:

[1] American Instrument Company, Silver Spring, Maryland.

[2] The Meriam Instrument Company, Cleveland, Ohio.

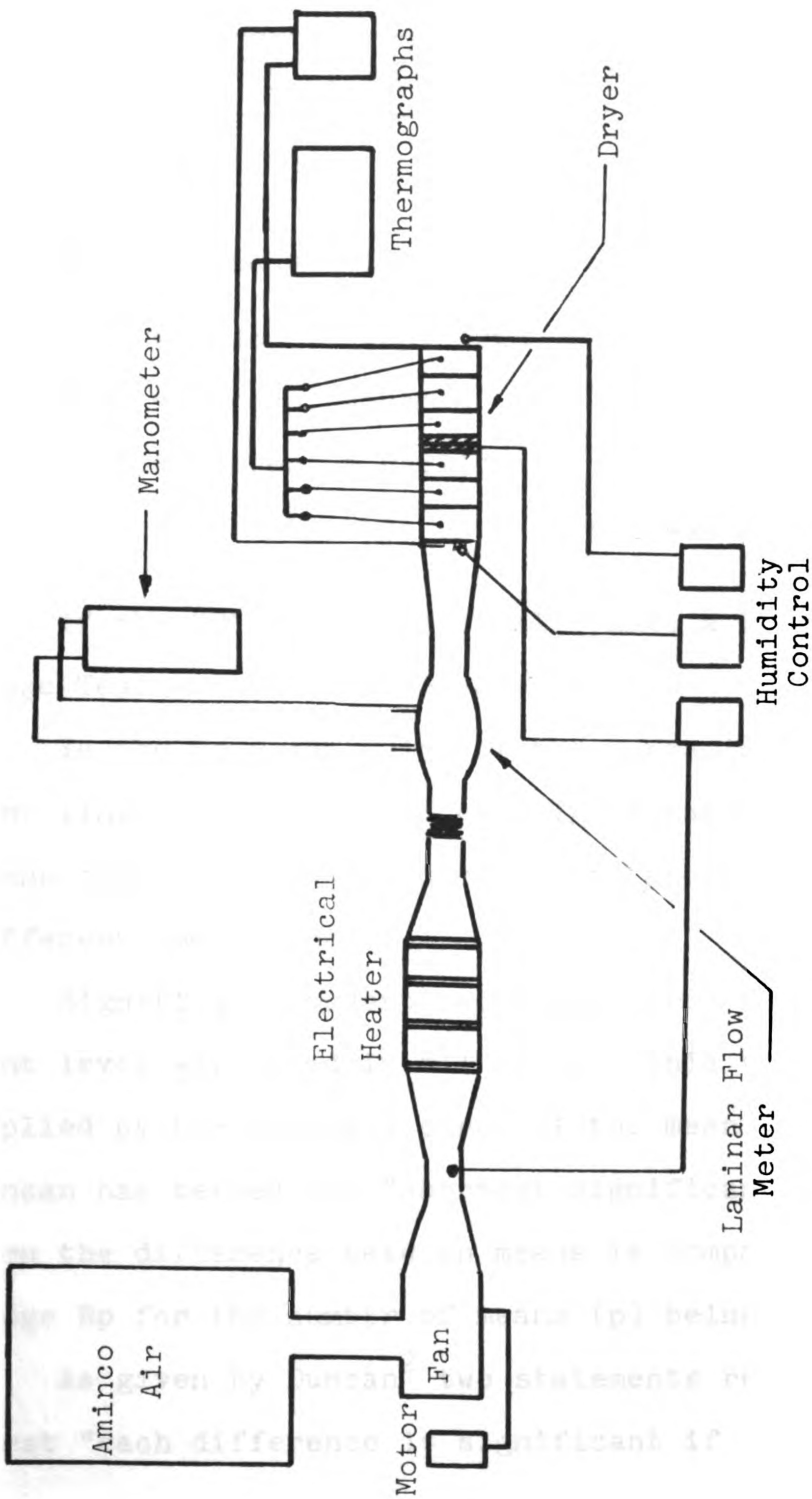

Figure 6. Arrangement of the drying set-up.

$$t = \frac{\bar{Y}_1 - \bar{Y}_2 - (u_1 - u_2)}{\left(\dfrac{\Sigma y_1^2 + \Sigma y_2^2}{n\,(n-1)}\right)^{1/2}}$$ [1]

$\bar{Y}_1$ = mean of sample one

$\bar{Y}_2$ = mean of sample two

Σy_1^2 = sums of squares

n = number of replicates

The hypothesis that $u_1 - u_2 = 0$ was tested.

If the "F" value was significant, a Duncan's Multiple Range Test was used to compare means.

In the representation of the Duncan's test results a line links all means with non-significance difference. The means that are not linked by a line are significant different among them.

Significant studentized ranges (rp) for the five percent level were used in all tests. This value (rp) multiplied by the standard error of the mean ($s\bar{y}$) gives what Duncan has termed the "shortest significant ranges" (Rp). Then the difference between means is compared against the range Rp for the number of means (p) being compared.

As given by Duncan[2] two statements resume the test, first "each difference is significant if it exceeds the

[1] Mendenhall, W. (1971).

[2] Cited by Le Clerg (1970).

corresponding shortest significant range, otherwise, it is not significant." Second is the exception rule "that no difference between two means can be declared significant if the two means concerned are both contained in a subset of the means which has a non-significant range."

A Paired-Difference "t" Test.

When comparing the HC (Hart-Carter) versus the MSU (Michigan State University) dryer and both against the control dryer, a paired difference "t" test was made. A pooled estimate of the common variance value of "t", for testing the hypothesis of $u_1 = u_2$, was compared with the tabulated "t" value in order to accept or reject the hypothesis.

CHAPTER IV

OBJECTIVES

A brief statement of the objectives of this study is given below:

1. Analyze and become acquainted with the existence of variability in corn quality tests.
2. Compare the Hart-Carter and the MSU dryers with respect to using high air temperature of drying.
3. Evaluate certified seed corn as affected by the MSU dryer.

CHAPTER V

RESULTS AND DISCUSSION

Variability of Results in Grain Quality Tests Due to Operator Effect.

Operators A, B, and C analyzed four U.S. No. 2 corn samples. The moisture content of the samples varied from 11 to 13 percent after four days in the grain conditioner. Each test included the evaluation of the three basic quality parameters breakage, germination and stress crack plus complementary analysis of moisture content and test weight.

All operators carried out the tests under the same ambient conditions.

A one-way analysis of variance for a completely randomized design of equal sample size was performed.

Influence of the Operator on Breakage Test Results.

The breakage test results are given in Appendix A. The "F" test (Appendix E) indicated non-significant operator effect ($\alpha = 25\%$). That means the operator is not an important source of variability when testing breakage with the Stein Corn Breakage tester.

Even though the test is exposed to personal errors when cleaning and choosing the samples, the results show that sample preparation has little influence on the outcome of the test.

The breakage test itself was not expected to be significantly affected by the operator since the machine tester is self-controlled in the functioning of its mechanisms and timer.

The applied breakage method is very dependable. It can be performed by different operators and still give the same results, if the moisture content and temperature of the sample are maintained constants at the test time.

Influence of the Operator on Germination Test Results.

The results of the germination tests (Appendix B) showed a non-significant operator effect ($\alpha = 50\%$) as indicated by the "F" statistics (Appendix E).

Low germination percentages were due to the condition of U.S. No. 2 corn coming from the 1972 harvest, which was unusual and a lot of damaged grain was present.

The germination test method used was a simple one. The use of garbage cans did not need an exact control of relative humidity and temperature. The 80°F box maintained the desired temperature. Relative humidity was kept uniform by placing a cover on the can.

Influence of Operator on Stress-Crack Test Results.

Inconsistency in the pattern to separate sound kernels, single cracks, double stress cracks, and checked kernels was found among operators.

Pictures of single and double cracks and checked kernels served as a guide for the operators to classify the kernels.

An analysis of variance of the results of the stress crack tests (Appendix F) shows the following results: there is a significant operator effect on the results of the stress crack test. The levels of significance for each type of stress crack are listed in Table 5-1. The data is given in Appendix D.

Table 5-1. Operator effect on stress crack test results.

Type of Stress Crack	Level of Significance Of Operator Effect
Sound Kernels	.5 %
Single Cracks	.1 %
Multiple Cracks	.1 %
Checked Kernels	.5 %

The significant difference for sound kernels can have two explanations: one due to the variance in the kernel itself or second due to the operator. The latter case is only explained when the operator does not examine the kernels in different positions.

The stress crack configuration is variable. This makes it very difficult to standardize the test and cancel the operator effect.

The technique allows the operator to develop his own criteria of classification when performing the test. Often, it is not clear how to classify a given kernel.

It is recommended that a few samples be analyzed before performing the actual test samples in order to become acquainted with the grain and be consistent.

Influence of the Operator on Test Weight and Moisture Content Test Results.

Test Weight.

This test is important from the point of view of U.S. corn standard classification. It also determines the moisture content correction by test weight (lb/bu) when using the Steinlite meter. One pound deviation from the actual test weight may change the moisture content reading as much as 0.25%.

Two factors may account for the difference between operators when measuring test weight: a) the operator reading of the weight, and b) variability of moisture content among samples. The "F" test (Appendix E) indicates, however, the operator effect on test weight result is non-significant (α= 10%).

Thus, the two mentioned factors did not affect the test and it can be reliable even when done by different operators.

It should be remembered that the moisture content of each sample was brought to equilibrium in the conditioner before testing.

Moisture Content.

The Steinlite and air-oven methods, as expected, had no significant differences at the five percent level (Appendix E). Test results are given in Tables 5-2 and 5-3.

Table 5-2. Moisture content result obtained with the Steinlite.

Moisture Content (%)			
Sample No.	Operator		
	A	B	C
4, 10, 1	11.26	11.75	11.63
12, 6, 8	11.65	11.36	11.65
5, 7, 2	11.00	11.59	11.46
3, 11, 9	10.97	11.26	11.44

Table 5-3. Moisture content results obtained with the Air-Oven.

Moisture Content (Oven Dry %)			
Sample No.	Operator		
	A	B	C
4, 10, 1	12.0	13.0	12.0
12, 6, 9	13.0	12.0	13.0
5, 7, 2	12.5	12.5	12.5
3, 11, 9	12.0	13.0	12.5

Steinlite and air oven methods of moisture content determination were not affected by the operator.

<u>Comparison of Corn Quality Parameters Between Hart-Carter and MSU.</u>

Air temperatures of 200°F and air humidity of 0.021 (lbs of water per lbs of dry air) were the drying conditions of the HC and MSU dryers. The temperature and humidity of the air during cooling were 67°F and 0.005 (lbs of water per lbs of dry air) respectively.

Control samples dried at 80°F and 75% relative humidity in the conditioner were compared with those dried with the Hart-Carter (HC) and MSU dryers.

Control samples were designated as 123-C, 126-C and 127-C.

To test breakage, stress-cracks and germination, samples had to be placed in the conditioner in order to decrease the moisture content to that recommended for the breakage test. The samples reached a moisture content of about 12.5 percent after four days.

Samples 123-MSU and 127-MSU, dried with the MSU dryer, gave a higher average moisture content after drying than the 123-HC and 127-HC samples, dried with the HC dryer (Table 5-4).

The initial moisture content was the same in both cases.

Temperature history showing the grain temperature

Table 5-4. Comparison of average moisture content after drying for HC and MSU samples.

Moisture	Samples			
Final Average Moisture Content %	123-HC	123-MSU	127-HC	127-MSU
	14.5	17.4	14.8	17.1

versus time for different sections of the MSU dryer are given in Appendix P. Only breakage and stress-cracks results were compared using a paired "t" test, since the germination data was meaningless.

The percent of germination was very low, from 0 to 3 percent, because the samples were kept at 10°F for a period of five months. Hall (1957) reported that corn with moisture content between 25 and 30 percent, decreased germination to 7 percent when kept at 8°F for 24 hours. Obviously, only very low germination could be expected after 5 months of storage at 10°F.

Stress Crack Comparison.

The number of stress cracks were found to be significantly different between samples dried in HC and MSU dryers (Table 5-5).

Sound kernels, single crack, multiple cracks and checked kernels had a significant difference at 2, 1, 1 and less than 0.1 percent level, respectively.

Table 5-5. Significant values of α for all comparisons of the dryers and control.

Comparison	Source			
	Sound	Single	Double	Checked
HC Dryer vs. MSU	2	1	1	< .001
HC Dryer vs. CONTROL	< .001	5	< .001	< .001
MSU Dryer vs. CONTROL	< .001	< .001	1	5

Detailed information about the paired "t" test is given in Appendix G. The data is given in Table 5-6.

The amount of damage in the HC dryer was higher than in the MSU dryer. The 123-MSU and 127-MSU samples, with higher moisture content after drying, presented fewer single crack, multiple cracks and checked kernels; consequently, the amount of sound kernels increased.

Samples dried with the HC and MSU dryer had the same residence time, but 123- and 127-MSU presented higher moisture content after drying (lower rate of drying). This could have affected the formation of stress-cracks and give a better quality of the grain.

Maximum grain temperatures, in the inlet hot side (MSU dryer), varied from 184 to 200°F. However, grain temperatures along the drying column were always lower. In the HC dryer, grain in the middle of the column reached temperatures that were 30°F lower than the highest temperatures. That

Table 5-6. Results of the stress-crack test for the control, HC and MSU dryers.

Control Samples			
Sample No.	123-C	126-C	127-C
Source	%	%	%
Sound	90.0	90.36	85.48
Single	5.8	3.61	3.76
Multiple	2.6	4.82	8.06
Checked	1.6	1.21	2.70
HC DRYER			
Sample No.	123-HC	126-HC	127-HC
Source	%	%	%
Sound	18.23	33.87	28.33
Single	16.57	12.36	15.00
Multiple	49.17	40.86	39.44
Checked	16.03	12.91	17.23
MSU DRYER			
Sample No.	123-MSU	126-MSU	127-MSU
Source	%	%	%
Sound	47.90	42.05	52.87
Single	12.57	11.36	12.64
Multiple	23.95	37.50	27.59
Checked	15.58	9.09	6.90

temperature difference ranged between 50 and 70°F for the MSU dryer.

The samples dried at a lower average temperature in the MSU dryer showed significantly lower values of stress-crack (Table 5-6).

The lower temperatures of the MSU samples at the initial cooling stage also contributed to the lower values of stress-cracks obtained with the MSU dryer.

Individually monitored moisture contents of the MSU samples showed that the grain in the middle of the column had from 3 to 5 percent higher moisture content than in the HC samples (Table 5-7).

Table 5-7. Percentage of final grain moisture content in the middle of the column of the HC and MSU dryers.

Samples					
123		126		127	
HC	MSU	HC	MSU	HC	MSU
16	20.9	15	18.5	17	20.6
15	20.4	14.5	18.5	15	18.7

The lower moisture content reduction (higher final moisture content) obtained in the MSU dryer may also have had some influence on the lower number of stress cracks.

HC and MSU samples were also compared against the control sample. The significant differences (Table 5-5) obtained between HC versus Control, and MSU versus Control, lead to the conclusion that the drying process significantly increased stress cracks.

For the HC dryer versus the Control, sound and checked kernels and multiple cracks had a significant difference at $\alpha < 0.001$ percent level, and single crack at 5 percent level. For MSU dryer and Control, sound kernels and single crack had a significant difference at $\alpha < 0.001$ percent level, multiple cracks at 1 percent and checked kernels at 5 percent level.

Breakage Comparison

The amount of breakage for samples dried in HC and MSU dryers was not significantly different ($\alpha = 90\%$).

Moisture content and number of stress cracks have been reported as factors causing breakage. Relating the grain moisture content difference of the HC and MSU samples (15 versus 17%), after drying, with the moisture content-breakage curve published by Thompson and Foster (1963), breakage would be increased to less than one percent. In the case of stress-cracks, it could increase the susceptibility to breakage.

Both HC and MSU samples were significantly different from the Control sample ($\alpha = 2\%$). The Control sample had breakage as much as 2 or 3 times less than that of the HC and MSU samples (Table 5-8).

Results of breakage are given in Table 5-8 and "t" test results in Appendix H.

Table 5-8. Percent of breakage obtained with the HC and MSU dryers, and Control sample.

Breakage (%)			
Sample No.	Treatments		
	Control	HC Dryer	MSU Dryer
123	6.1	11.0	14.4
126	7.2	15.0	21.8
127	5.5	18.0	10.4

Analysis of Quality Factors for Certified Seed Corn Dried Artificially.

Influence of the grain temperature and moisture content gradients on grain damage, along the dryer column, could not be measured because no samples were available for the intermediate stages of the HC dryer.

The MSU dryer permitted the analysis of quality factors in each section (the dryer had six sections separated by a metallic screen) under the same conditions used as with the HC dryer.

Moisture Content After Drying.

Average moisture content varied from 17 to 19 percent in all samples (123-S, 126-S and 127-S). The distributions

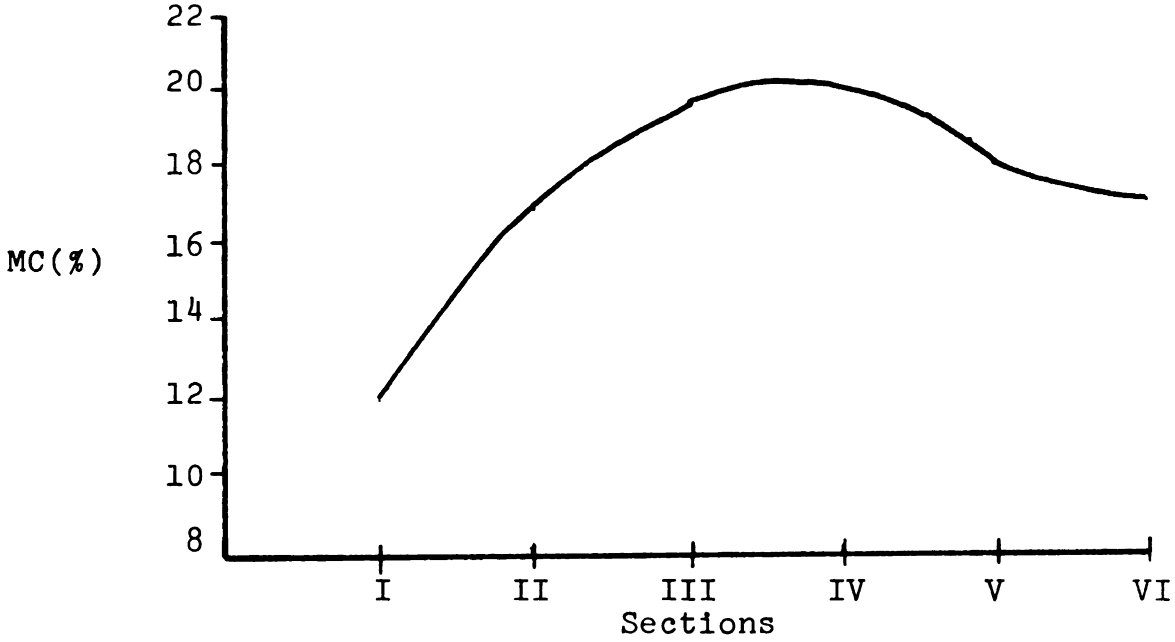

Figure 7. Final grain moisture content along the dryer in 123-S sample.

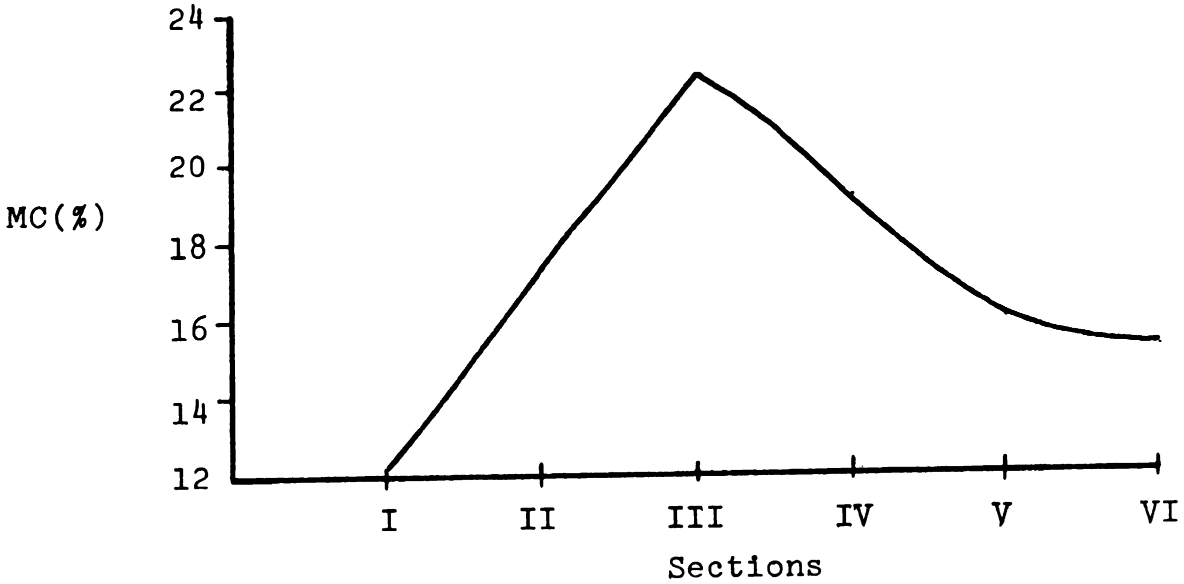

Figure 8. Final grain moisture content along the dryer in 126-S sample.

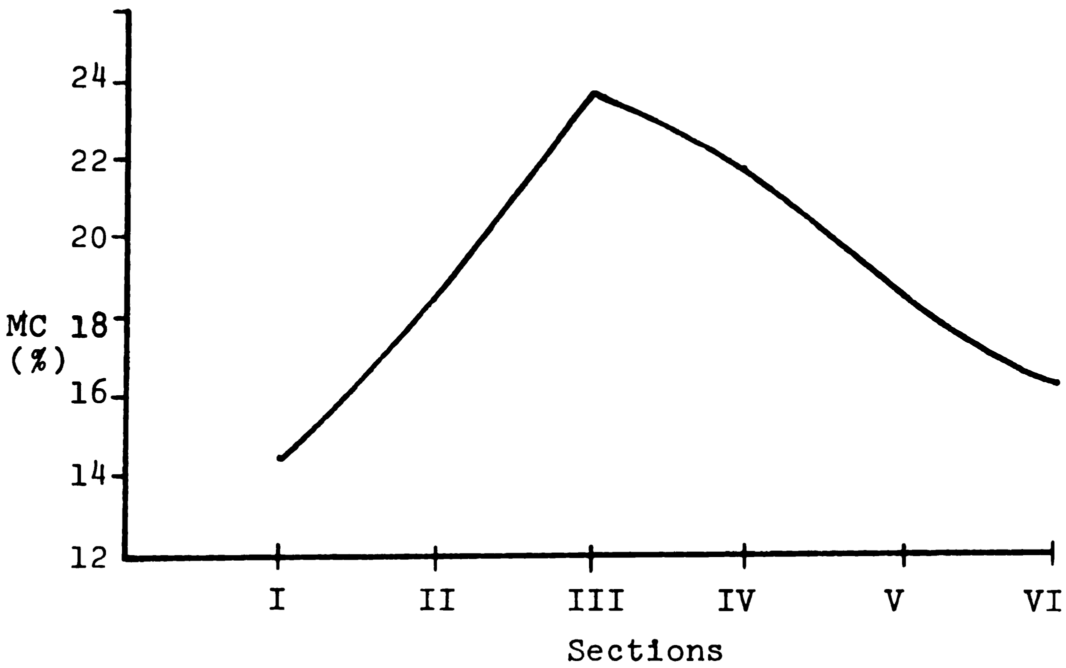

Figure 9. Final grain moisture content along the dryer in 127-S sample.

of moisture content are shown in Figures 7, 8 and 9. The moisture content distribution of each test is given in Appendix J.

The grain exposed to hot air (Section I) in the first stage of drying had the lowest moisture content. Section VI exposed to hot air in the second stage had the second lowest moisture content. The middle sections presented moisture contents only 2 percent below the initial moisture (25%).

All samples were conditioned to 12 percent of moisture content before the quality tests were performed.

The effect of drying on grain quality was determined by means of a one-way AOV. In tests where drying effect on grain quality was significant, a Duncan's test was used to compare the treatments. If the drying effect was non-significant, only comparison between treatments that were considered likely to be different before actually collecting the data (priori test), were compared using a "t" test.

Stress Crack Evaluation.

Twenty-two stress-crack analyses were carried out. Each section of the dryer represented a treatment in the one-way AOV.

The one-way analysis of variance shows that the percentage of sound kernels, multiple cracks and checked kernels was significantly affected ($\alpha = 5\%$) by the drying process (Appendix L). Single crack was not significantly affected (α = 5%) by drying (Appendix L). The data is given in Appendix K.

Since there was a significant effect of drying on sound kernels, the means of the multiple crack and checked kernels were compared with the Duncan's test.

Duncan's test results, for significant "F" test, are given in Tables 5-9, 5-10 and 5-11.

Table 5-9. Duncan's test results for sound kernels.

Treatments	VI	V	I	II	III	IV	S-C
Means	10.15	10.23	15.39	15.87	18.0	18.45	26.65
Results	——	——	——	——	——	——	——

Table 5-10. Duncan's test results for multiple cracks.

Treatments	S-C	I	II	III	IV	V	VI
Means	46.72	60.58	60.87	61.84	62.98	68.06	70.64
Results	——	——	——	——	——	——	——

Table 5-11. Duncan's test results for checked kernels.

Treatments	IV	V	II	III	S-C	VI	I
Means	1.86	2.13	2.50	2.51	2.66	3.17	6.87
Results	——	——	——	——	——	——	——

The percentage of sound kernels in Sections III and IV was not significantly different from that of the control sample (Table 5-9). The lower moisture content reduction obtained in this sections as well as the lower drying temperatures explain the result.

The multiple cracks percentage was not significantly different among sections, but all sections were significantly different from the control sample (Table 5-10).

The percentage of checked kernels was significantly higher in Section I (Table 5-11). The rate of temperature increase was considerably higher for Section I, since it was exposed to the inlet drying air (200°F) directly from room temperature. Also, the moisture content reduction in Section I was higher than in any other section. This partially explains the higher percentage of checked kernels.

The temperature history of the grain during drying (Appendix P) showed a variation from 100°F in Sections II and IV to 200°F in Sections I and VI.

Moisture content of the grain was higher for the central sections (III and IV) of the dryer.

Sections where the grain temperature reached 200°F were expected to have more damaged grain than those where the grain reached only 100°F. The data shows differences between sections, but they were not large enough to be detected by statistical analysis. The grain moisture content after drying did not affect the stress-crack number in the sections either.

Corn in Sections III and IV had the highest moisture content after drying. In the first stage of drying, moisture picked up in Sections I and II is carried through Sections III, IV, V and VI. In the second stage, moisture from Sections V and VI is carried through Sections IV, III, II and I.

Heated water vapor might have condensed in the middle sections, where corn had a lower temperature. This might explain the high moisture content of Sections III and IV.

Well known is that grain cooled rapidly increases in the number of stress-cracks. Section VI in all samples was exposed to this condition but stress-cracks were not significantly increased.

As the effect of drying on the number of single cracks was not significant, means were compared with the "t" test.

The "t" test results (Table 5-12), comparing means, gave a significant difference ($\alpha = 5\%$) on single crack of the control against Sections I, III, IV and V.

The effect of drying on single crack for sections II, VI and the control was not significant ($\alpha = 5\%$).

Table 5-12. Results of "t" test used to compare means, of single crack for dryer sections and control sample.

Treatments	I	II	III	IV	V	VI
Control	6.39*	2.50	6.56*	3.41*	3.43*	1.84

Breakage Evaluation.

Breakage was significantly affected ($\alpha = 5\%$) by drying (Appendix M). Thus, Duncan's test was used to compare means. Duncan's test results (Table 5-13) show that breakage in Section I was significantly different ($\alpha = 5\%$) from breakage in Sections III, IV, V, II, VI and the control ($\alpha = 5\%$) as shown by Duncan's test (Table 5-13). The data is given in Appendix A.

Table 5-13. Duncan's test results for breakage.

Treatments	S-C	III	IV	V	II	VI	I
Means	12.63	12.8	13.43	16.66	17.26	19.56	28.1
Results	————	————	————	————	————	————	————

Susceptibility to breakage depends on the number of stress-cracks and level of moisture content.

The severe conditions to which Section I was exposed could be related to the high breakage in that section. Residence time of hot air of drying was longer for Section I (30 minutes). The grain in that section reached the maximum drying temperature and lowest moisture content. Grain temperature in Section VI was the same as in Section I, but moisture content was higher. Section VI had shorter residence time (19 minutes) than Section I. Section VI had the second highest percentage of breakage.

Germination Evaluation.

Germination was significantly affected ($\alpha = 5\%$) by drying (Appendix N). The data is given in Table 5-14. The Duncan's test results (Table 5-15), to compare means, show that all section means were significantly different ($\alpha = 5\%$) from control.

Table 5-14. Germination results in seed corn.

Sample No.	Treatments						
	Control	I	II	III	IV	V	VI
123-S	40	0	0	18	12	2	0
126-S	32	0	0	17	5	2	0
127-S	36	0	0	12	25	3	0

Table 5-15. Duncan's results for germination.

Treatments	I	VI	II	V	IV	III	S-C
Means	0	0	1.66	2.33	14.0	15.66	36
Results	----------	----------	----------	----------	----------	----------	

The grain temperature in Sections I, VI, II and V reached values that varied between 160°F and 200°F. Watson (1960) studied the effect of drying conditions on germination in an experimental bacth dryer and found that temperatures of 160°F or above reduced germination to 0%. Watson used two initial grain moisture contents (32 and 21%) and two relative humidities of drying air (40 and 15%) (Table 5-16).

Table 5-16. Percentage of germination at different temperatures of drying, initial moistures of grain and relative humidity of drying air according to Watson (1960).

Air Temperature °F	32% Initial Moisture		21% Initial Moisture	
	Relative Humidity of Drying Air			
	40%	15%	40%	15%
160°	0	0	0	0
180°	0	0	0	0
200°	0	0		

The seed control sample had a 99% germination before rewetting. The rewetted grain maintained in a 40°F box for 5 to 7 days decreased germination to an average of 36 percent. Hall (1957) mentioned the same relation of germination reduction when grain is rewetted.

CHAPTER VI

CONCLUSIONS

1. Breakage and germination, test weight and moisture content determinations can be performed by different operators.
2. Stress-crack determinations by candling can only be performed by one operator. Adequate training before performing final tests is necessary.
3. The number of stress-cracks were significantly increased by the HC and MSU dryers compared to the control.
4. The number of stress-cracks were significantly different in the HC and MSU dryers.
5. Breakage percentage was not significantly affected by the HC and MSU dryers.
6. The number of checked kernels at the different locations in the drying column was a function of the temperature and moisture content of the grain reached during drying.
7. Increased grain breakage was observed in Section I (MSU dryer) exposed to the highest temperature for a long period of time. The percentage of breakage in Section I was significantly different from the

amount sections and the control. Germination was also significantly different in Section I as compared with Sections III and IV and the control.

8. The percentage of broken kernels in the sections was the same probably because the number of stress-cracks was not significantly different among sections.
9. Sections I and VI exposed to 200°F air temperature gave 0 percent of germination.

APPENDICES

APPENDIX A

Table A-1. Percentage of breakage in U.S. No. 2 corn.

Breakage (%)			
Sample No.	Operator		
	A	B	C
4, 10, 1	13	12	16
12, 6, 8	13	12	12.3
5, 7, 2	11.5	11	12.2
3, 11, 9	12.4	10	12.3

APPENDIX B

Table B-1. Percentage of germination in U.S. No.2 corn.

Germination (%)			
Sample No.	Operator		
	A	B	C
4, 10, 1	15	11	11
12, 6, 8	9	10	13
5, 7, 2	23	9	12
3, 11, 9	12	13	14

APPENDIX C

Table C-1. U.S. No. 2 corn test weight.

Test Weight (lbs/bu)			
Sample No.	Operator		
	A	B	C
4, 10, 1	56.0	54.0	54.0
12, 6, 8	55.0	54.5	53.5
5, 7, 2	55.0	54.0	54.5
3, 11, 9	54.0	54.5	53.5

APPENDIX D

Table D-1. U.S. No. 2 corn stress crack results.

Sample No.	Operator A	Operator B	Operator C
Sound Kernels (%)			
4, 10, 1	23.39	32.00	31.4
12, 6, 8	17.75	34.60	20.13
5, 7, 2	18.75	36.00	17.74
3, 11, 9	20.12	33.00	16.67
Single Crack (%)			
4, 10, 1	17.54	30.00	30.0
12, 6, 8	18.34	26.00	30.52
5, 7, 2	18.19	23.00	30.65
3, 11, 9	13.41	23.00	30.36
Multiple Cracks (%)			
4, 10, 1	35.68	23.00	20.6
12, 6, 8	33.73	23.00	25.32
5, 7, 2	39.20	26.00	20.16
3, 11, 9	37.20	21.00	24.40
Checked Crack (%)			
4, 10, 1	23.39	15.00	18.00
12, 6, 8	30.18	17.00	24.03
5, 7, 2	23.66	15.00	31.45
3, 11, 9	29.27	23.00	28.57

APPENDIX E

Table E-1. "F" significance of different quality tests, using U.S. No. 2 corn.

Source	Fs Calculated	Percent Level ( )	$F_{(2,9)}$
Breakage	2.37	0.25	1.62
Germination	1.18	0.50	0.749
Test Weight	4.02	0.10	3.01
Moisture Content	2.26	0.05	4.26
Moisture Content*	.30	0.05	4.26

* Oven dry.

APPENDIX F

Table F-1. "F" significance of stress crack, using U.S. No. 2 corn.

Type of Stress Crack	Fs Calculated	Percent Level ( )	$F_{(2,9)}$
Sound Kernels	12.48	0.005	13.6
Single Crack	34.00	0.001	22.9
Multiple Crack	44.40	0.001	22.9
Checked Kernels	4.88	0.05	4.26

APPENDIX G

Table G-1. Values of "t" used to compare stress crack among HC and MSU dryers, and then versus the control.

Type of Stress Crack	HC Dryer Vs.MSU Dryer	HC Dryer Vs. Control	MSU Dryer Vs. Control
Sound	3.75*	12.77***	11.76***
Single	6.21**	3.30*	9.51***
Multiple	8.53**	11.11***	5.64**
Checked	10.60***	9.96***	3.28*

t (4) (0.025)

APPENDIX H

Table H-1. Value of "t" used to compare breakage between HC and MSU dryers, and control.

Comparison	"t" Value
HC Dryer and MSU Dryer	.22
HC Dryer and Control	4.03
MSU Dryer and Control	2.78

APPENDIX J

Table J-1. Grain moisture content in each section.

Moisture Content (%)			
Section	Sample No.		
	123-S	126-S	127-S
I	11.97	12.09	14.41
II	17.04	17.50	18.65
III	19.63	22.50	23.74
IV	20.51	19.52	21.98
V	18.01	16.35	18.48
VI	17.20	15.65	16.41

APPENDIX K

Table K-1. Percentage of stress crack in seed corn.

Sample No.	Control	I	II	III	IV	V	VI
Sound Kernels (%)							
123-S	28.75	13.12	14.81	14.38	11.88	7.10	7.64
126-S	26.66	23.46	17.79	25.16	22.22	14.84	14.01
127-S	24.54	9.61	15.03	14.46	21.25	8.75	8.80
Single Crack (%)							
123-S	22.50	16.88	14.81	18.12	20.62	13.55	15.92
126-S	24.24	18.52	21.47	18.86	17.90	17.42	24.20
127-S	25.15	16.03	19.61	18.87	15.00	20.00	15.72
Multiple Cracks (%)							
123-S	45.63	65.62	67.78	63.75	66.25	76.13	73.89
126-S	46.06	46.91	58.28	55.34	57.41	65.81	58.60
127-S	48.47	69.23	63.40	63.52	61.88	70.00	71.70
Checked Kernels (%)							
123-S	3.12	4.38	3.10	3.75	1.25	3.22	2.55
126-S	3.04	11.11	2.46	.64	2.47	1.93	3.19
127-S	1.84	5.13	1.96	3.15	1.87	1.25	3.78

APPENDIX L

Table L-1. "F" test significance for stress cracks in seed corn.

Type of Stress Crack	Fs (Calculated)	$F_{(6,14)}$ (.05)
Sound	4.20*	2.85
Single	2.06	2.85
Multiple	4.01*	2.85
Checked	3.25*	2.85

Table L-2. "F" test significance for breakage and germination in seed corn.

Source	Fs (Calculated)	$F_{(6,14)}$ (.05)
Breakage	4.60*	2.85
Germination	26.68*	2.85

APPENDIX M

Table M-1. Percentage of breakage for seed corn.

Sample No.	Breakage: Treatments						
	Control	I	II	III	IV	V	VI
123-S	12.6	28.9	18.8	14.7	14.9	15.6	17.5
126-S	12.3	37.4	19.3	11.1	15.3	20.4	23.0
127-S	13.0	18.0	13.7	12.6	10.1	14.0	18.2

APPENDIX N

Table N-1. Percentage of germination in seed corn.

Sample No.	Germination: Treatments						
	Control	I	II	III	IV	V	VI
123-S	40	0	0	18	12	2	0
126-S	32	0	0	17	5	2	0
127-S	36	0	5	12	25	3	0

APPENDIX P

Table P-1. Grain temperature history of drying the 123-MSU sample in the MSU dryer sections.

	Time min.	Dryer Sections					
		I	II	III	IV	V	VI
First Stage of Drying	0	59	65	60	60	67	55
	5	148	101	96	96	87	73
	10	184	126	98	98	95	98
	15	197	146	104	104	95	97
	20	200	156	115	115	95	98
	25	200	166	136	136	96	98
	30	200	170	120	120	96	108
Second Stage of Drying	35	130	110	100	100	98	157
	40	109	102	108	108	108	198
	45	109	107	130	130	124	200
	50	116	114	133	133	118	144
Cooling Stage	55	114	114	107	107	88	76
	60	90	89	78	78	76	71
	65	75	78	72	72	74	71
	70	72	74	72	72	74	71

Table P-2. Grain temperature history of drying of the 126-MSU sample in the MSU dryer sections.

	Time	Dryer Sections					
	min.	I	II	III	IV	V	VI
First Stage of Drying	0	96	92	46	46	90	36
	5	106	88	88	88	81	66
	10	121	93	93	93	84	93
	15	128	98	94	94	87	94
	20	135	102	100	100	89	94
	25	142	110	114	114	89	95
	30	146	114	129	129	91	95
Second Stage of Drying	35	120	108	96	96	92	150
	40	110	102	102	102	94	185
	45	103	100	120	120	107	184
	50	100	102	132	132	120	184
Cooling Stage	55	99	102	128	128	114	136
	60	98	100	122	122	110	90
	65	95	97	106	106	97	75
	70	94	93	94	94	88	73
	75	90	90	82	82	80	73

Table P-3. Grain temperature history of drying of the 127-MSU sample in the MSU dryer sections.

	Time min	Dryer Sections					
		I	II	III	IV	V	VI
First Stage of Drying	0	62	65	44	44	34	34
	5	100	70	74	74	48	34
	10	142	86	91	91	90	74
	15	170	92	94	94	94	91
	20	183	96	95	95	95	93
	25	188	100	95	95	95	94
	30	197	104	101	101	96	94
Second Stage of Drying	35	154	103	95	95	93	110
	40	113	99	93	93	92	152
	45	100	95	93	93	105	175
	50	99	94	100	100	128	184
Cooling Stage	55	102	103	102	102	132	170
	60	94	94	97	97	134	100
	65	90	86	97	97	112	77
	70	84	83	90	90	88	74

Table P-4. Grain temperature history of drying of the 123-S sample in the MSU dryer sections.

	Time min	Dryer Sections					
		I	II	III	IV	V	VI
First Stage of Drying	0	50	50	50	50	39	38
	5	142	101	77	77	80	68
	10	185	103	82	82	102	104
	15	198	109	86	86	103	105
	20	200	127	91	91	103	106
	25	200	150	92	92	104	106
	30	200	159	94	94	104	106
Second Stage of Drying	35	152	113	95	95	103	126
	40	118	107	97	97	109	176
	45	112	107	95	95	127	194
	50	112	104	96	96	157	200
Cooling Stage	55	104	104	92	92	126	94
	60	101	97	78	78	85	85
	65	88	82	73	73	75	76
	70	77	75	71	71	74	76

Table P-5. Grain temperature history of drying of the 126-S sample in the MSU dryer sections.

	Time min	Dryer Sections					
		I	II	III	IV	V	VI
First Stage of Drying	0	90	57	48	48	49	42
	5	105	93	90	90	67	50
	10	144	98	100	100	95	94
	15	173	100	101	101	102	102
	20	198	112	103	103	101	107
	25	194	138	100	100	102	107
	30	200	156	107	107	99	102
Second Stage of Drying	35	114	100	99	99	104	160
	40	104	95	100	100	136	200
	45	103	97	112	112	157	200
	50	107	100	116	116	157	188
Cooling Stage	55	104	108	110	110	135	165
	60	96	104	100	100	124	144
	65	91	100	94	94	116	129
	70	85	93	90	90	110	114
	75	80	88	86	86	104	99

Table P-6. Grain temperature history of drying the 127-S sample in the MSU dryer sections.

	Time min	Dryer Sections					
		I	II	III	IV	V	VI
First Stage of Drying	0	88	64	50	50	46	60
	5	104	93	56	56	83	62
	10	134	94	90	90	94	93
	15	150	95	95	95	93	96
	20	164	109	96	96	93	96
	25	168	125	95	95	94	96
	30	174	134	96	96	94	96
Second Stage of Drying	35	132	101	96	96	100	110
	40	105	96	96	96	96	160
	45	102	96	97	97	105	189
	50	102	100	98	98	120	198
Cooling Stage	55	104	98	94	94	112	172
	60	100	92	83	83	109	128
	65	91	83	79	79	104	106
	70	85	77	72	72	90	80

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