ANALYSIS OF MOISTURE CONTENT AND HEAT DAMAGE OF WHEAT USING PHYSICAL TECHNIQUES

by

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INTRODUCTION

Moisture content in wheat is a matter of great importance. Miller and Johnson (1954) reported that moisture content is related to the quality of wheat and flour in at least three important ways, namely: (1) flour yield varies inversely with moisture content; (2) composition percentages of protein, starch, and other substances of nutritive value are inversely related to percentages of moisture; and (3) deterioration of grain during storage may depend on the moisture relationships in the wheat kernel (1). The flour miller, in particular, is concerned with the moisture content of the grain as bought, of the stocks during milling, and of the final products. Satisfactory conditioning requires accurate knowledge of moisture content. Similarly, every processor of cereals requires information regarding the moisture content of the raw material and the products with which he is dealing, Also it is well known that difficulties will arise if cereal goods are stored with too high a moisture content (2). Among the more important difficulties encountered in wheat as a result of improper conditioning are stress cracks which increase the susceptibility of the individual wheat kernels to attack by molds, yeasts, and other microorganisms (3). These forms of growth are particularly injurious to wheat in that for their subsistence they feed on the foodstuff of the wheat kernel in their immediate vicinity thereby detracting from the nutritive value of the wheat. Milner and Geddes (1946) dealt with this problem and came to the conclusion that in damaged grain the nutrients are more readily available to molds than in sound grain, and that mold growth can therefore occur in damaged grain at a lower moisture level (4). Another related conclusion arrived at by Milner et al. (1959) was that natural weathering (wetting and drying) or grain tempering prior to milling creates an additional internal endosperm stress which, when added to the maturing stress, causes the stress within the endosperm to exceed the breaking point, thus producing cracks. Secondary cracks, arising from the primary cracks, radial and transverse from the crease at moisture levels used in tempering, break up the endosperm into particles in the size range of wheat middlings (5).

Wheat from various climates shows a range of moisture content. While it is not known precisely how and where the moisture is combined in wheat, it does seem to be present in several distinct states. A certain amount of water may be held in the intergranular spaces and within the pores of the material. Such water may be termed free water, i.e., it possesses its usual properties, and the molecules of the absorbing substance are not concerned except as a supporting structure. Another portion of the water is more closely associated with the absorbing substance. There is an interaction between the water molecules and those of the absorbing substance. In this situation the properties of one substance influence the properties of the other. Water is then said to be adsorbed. Finally, some water may combine in a chemical union with the absorbing substance; and as a result, water which is an integral part of a given substance may be removed only with difficulty, e.g., at high temperatures and when driven off may cause an alteration in the character and constitution of the wheat kernel (3). Thus, when wheat is heated, a loss of moisture occurs. This loss is fairly rapid initially which is probably due to the release of absorbed moisture, but as the temperature continues to rise and the amount of moisture given off increases, it becomes increasingly difficult to remove further adsorbed moisture. It is difficult to draw a sharp line of division between the three types of moisture in a cereal grain and therefore the determination of moisture content becomes an empirical process in which strict control of conditions must prevail if comparable results are to be obtained (2).

The basic problem with which this thesis is concerned is the determination of relationships which might exist between the manner in which a wheat kernel retains its moisture and the amount of heat damage to which the specimen had been previously subjected. The rate at which moisture leaves the grain depends upon how much the grain is out of equilibrium with the environment surrounding it, on the temperature, and on the nature, size, and shape of the kernels (3). Once stress cracks have been produced in wheat as a result of, for example, improper tempering, as the treatment of wheat grain with moisture and usually with heat also is referred to, they cannot be removed or repaired and consequently alter many physical properties of not only the wheat but also the resulting milled flour. Thus, the manner in which moisture is released by the wheat grain could be used not only in determining the moisture content of the grain, but also possibly could be used in the evaluation of the quality of the wheat to be milled.

EXPERIMENTAL PROCEDURE

Testing Procedure

The problem of determining any relationships existing between damage and rate of moisture evolution in wheat was approached in the following manner. Wheat samples were first damaged to varying degrees by means of excessive and prolonged heating which in some instances was preceded by soaking the sample in water. X ray radiographs were then taken of a certain number of kernels of each sample, which R.T. Cotton states is the most accurate and rapid method of determining internal damage in samples of grain (6). The x ray radiographs were then visually scanned and a comparison was made among the samples to determine the extent of damage produced in the individual wheat kernels. This enabled a statistical comparison of the total number of cracks in each sample to be made. In addition to this visual inspection, the radiographs were then passed through a microphotometer in which a scanning light beam detected minute cracks in damaged kernels and, by means of an electronic recorder, produced graphical tracings of each sample member. The results of visual inspection were then correlated with the light beam tracing for the purpose of evaluating the microphotometer technique as a tool in wheat damage analysis. With the damaged wheat samples graded on a statistical basis, a specific amount of each sample was then placed in a small vacuum chamber and the vapor pressure of the sample in equilibrium with its surroundings was measured at various temperatures. From the resulting data, using water as a reference, the sample's vapor pressure and relative humidity under equilibrium conditions were determined and plotted as functions of temperature.

Apparatus

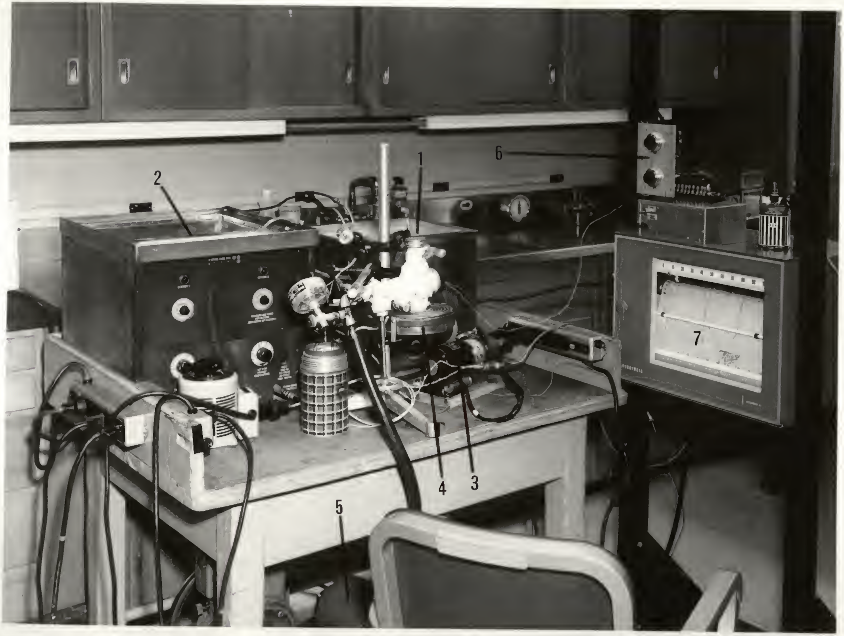
Two sets of apparatus, basically similar in structure and function, were used in testing the moisture releasing properties of the wheat samples. In Plate I is shown Apparatus I and Apparatus II is pictured in Plate II with several of the more essential components labeled. Both sets of apparatus included a vacuum pump used for the evacuation of the chamber within which the tests were conducted. The pumps reduced the pressure within the chambers to a value of the order of a millimeter. Also included in each apparatus was a variable temperature water bath the contents of which were circulated, by means of water pumps, through copper tubing attached to and surrounding the vacuum chamber containing the sample. This experimental design permitted the temperature within the vacuum chamber to be controlled by manipulation of the heating and cooling

EXPLANATION OF PLATE I

A photograph of Apparatus I.

1. Variable temperature water bath
2. Constant temperature water bath
3. Water pumps
4. Vacuum chamber
5. Vacuum pump
6. Wheatstone bridge circuit
7. Recorder

PLATE I

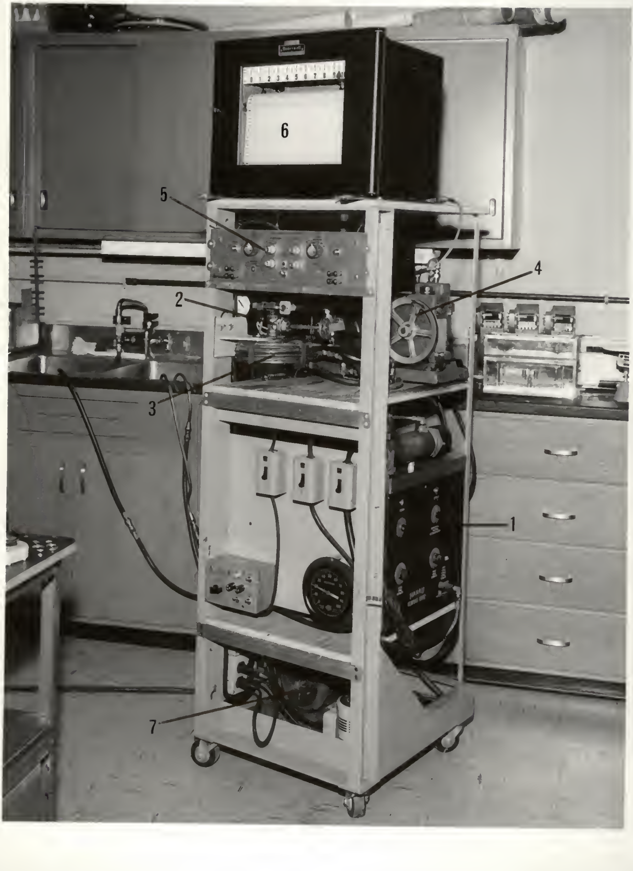


EXPLANATION OF PLATE II

A photograph of Apparatus II.

1. Variable temperature water bath
2. Constant temperature heating coils
3. Vacuum chamber
4. Vacuum pump
5. Amplifier
6. Recorder
7. Water pump

PLATE II



mechanisms of the variable temperature water bath. A thermostatically controlled heater was used for increasing the temperature of the water bath, while cooling was carried out by running cold water through copper tubing within the bath itself. The short pipe connection between the vacuum chamber and vacuum pump inlet, in each apparatus, was kept at a constant temperature which was greater than the maximum temperature to which the samples were subjected. In Apparatus I this was carried out by means of a hot water bath the contents of which were circulated by means of water pumps through copper tubing surrounding this short connection. In Apparatus II this connection was maintained at a relatively higher constant temperature by means of heating coils wrapped around it. The purpose of keeping this upper chamber at a relatively higher constant temperature was to insure against the condensation of any moisture evolved during testing on a colder part of the vacuum chamber. Any such condensation would limit the vapor pressure to the saturation value at that temperature thereby reducing the sensitivity of the apparatus in the detection of moisture.

Two types of sensing devices were used for these experiments. In Apparatus I an electrolytic sensor was employed. It consisted of a thin plate of glass covered on both of its flat sides with a carbon compound the resistance of which varied as a function of the amount of moisture collected on it. In Apparatus II the sensing device used was a strain gauge assembly sensitive to changes in pressure. Both sensors made up one branch of a Wheatstone bridge as shown in Plate III. As the equilibrium vapor pressure of a wheat sample changed as its environmental temperature was increased, the current through the sensing device changed resulting in the unbalancing of the bridge. This unbalanced bridge signal was then fed to an amplifier and then on to a recorder.

Pre-Testing Treatment of Samples

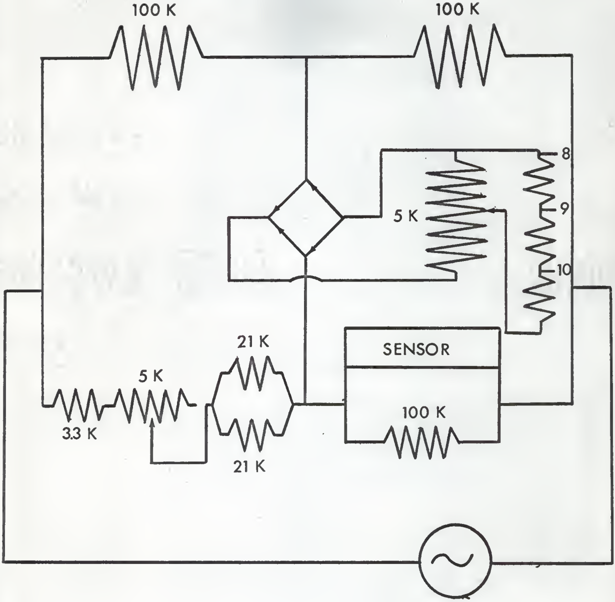
Prior to these experiments two varieties of wheat, an Ottawa blend and a Gaines wheat, were damaged to varying degrees. The Ottawa blend, a Hard Red Winter wheat, will subsequently be referred to as Sample 67-6001 and the Gaines sample, a Soft White Western wheat, will be referred to as Sample 67-6005. The pre-testing treatment of these wheats is indicated in Table 1.

In addition to the initial damaging treatments, portions of the undamaged and damaged samples were subjected to other types of alterations. One such treatment involved bringing all samples to a nearly uniform moisture content before being tested, while another involved inoculating a series of samples with the mold *Aspergillus chevalieri* prior to testing. Closely related to the mold inoculating treatment was the situation in which samples were treated in the same manner as the molded samples, however no molding was caused by direct inoculation. This involved bringing the moisture content of the grain up

EXPLANATION OF PLATE III

A wiring diagram of the Wheatstone bridge circuit.

PLATE III


100 K
100 K
8
9
5 K
10
SENSOR
21 K
5 K
3.3 K
21 K
100 K

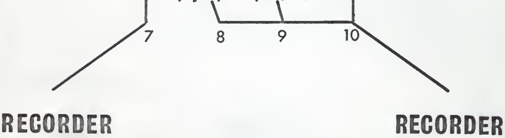

1K
1K
3K
7
8
9
10
RECORDER
RECORDER

Table 1. Pre-testing Treatment of Wheat Samples

67-6001 and 67-6005.

Sample	Treatment	Moisture Content-% (Wet Basis)
67-6001 Control	———	11.83
67-6005 Control		10.29
67-6001 A	Fan dried 7 hrs.	12.52
67-6005 A		10.59
67-6001 B	Heated at 60°C 2 hrs.	7.80
67-6005 B		8.79
67-6001 C	Soaked in distilled water 2 hrs., heated at 60°C 4 hrs.	12.77
67-6005 C		12.96
67-6001 D	Soaked in distilled water 2 hrs., heated at 80°C 4 hrs.	11.59
67-6005 D		7.39
67-6001 E	Soaked in distilled water 12 hrs., heated at 80°C 6 hrs.	6.92
67-6005 E		7.45

to 17% by keeping the environmental relative humidity at 85% for a temperature of 30°C.

Testing of Samples

The procedure used in testing a sample was the following. A carefully weighed amount of a particular sample was placed in the testing chamber which was then evacuated by a vacuum pump. In Apparatus I 12.5 g of wheat was the standard amount employed in the experiments, while in Apparatus II, because of its larger vacuum chamber, the test samples were 25.0 g. These particular weights were used for primarily two reasons. One reason was that this amount of wheat was considered to be large enough to accurately represent any random sample of the test groups involved. The other reason was related to the size of the test chambers involved. It was found that these two weights provided an amount of wheat which formed a layer one kernel thick on the inner, lower surface of each test chamber. Thus, temperature gradients within the wheat samples being tested were reduced.

Temperature control of specimens was carried out by two methods. In Apparatus I the test chamber temperature was increased in incremental steps over the approximate temperature range of 17° to 53°C. This temperature range was covered in ten steps where, at the end of each temperature increment, the temperature would level off to a constant value so as to allow the sample to come to thermal equilibrium with its surroundings. This, it was found, also allowed the sample to attain vapor pressure equilibrium with the surrounding evacuated test chamber. In Apparatus II temperature increments were not used, but rather the temperature was slowly and continuously increased over a temperature range of approximately 17°to 87°C. Although in this procedure samples were not kept at constant temperature for any length of time, the slow rate of increase of temperature allowed the samples to very closely approach equilibrium conditions.

At the conclusion of a test run, when the maximum temperature had been reached, the apparatus was then cooled by means of cold water circulating in tubing within the variable temperature water bath. The sample was then removed from the test chamber and, with the exit valve opened, any residual moisture was removed from the chamber by means of the vacuum pump.

Water was used in the calibration of the apparatus. In a typical calibration run, water in the test chamber was subjected to various environmental temperatures and, after referring to vapor pressure tables of water at various temperatures in the Handbook of Chemistry and Physics, recorder deflections were labeled with the appropriate vapor pressure. Similarly, the test chamber temperature was calibrated by noting temperatures of the variable temperature water bath and ascribing these values to the corresponding recorder deflections.

Presentation of Results

With the apparatus calibrated, wheat samples were tested and the relationship between two variables, equilibrium vapor pressure and temperature, was recorded. These data were then represented graphically with temperature plotted along the abscissae and equilibrium vapor pressure along the ordinates. From these graphs relative humidity values at various temperatures were determined and also plotted as functions of temperature.

X Ray Equipment and Technique

A Picker 0-50 Kv Industrial X ray Unit was used in the x ray analysis. This unit contains an AEG-50 tube which is a beryllium-windowed, grounded-anode x ray tube designed to provide high intensity, long-wavelength x radiation. In making the radiographs Kodak Type M (M-54) Industrial X ray film was exposed within the time limits of 7 to 15 sec. at a tube rating of 10 ma and 20 PKV.

The samples were placed on a lucite plate of dimensions 11.5 mm x 11.3 mm x 0.6 mm which contained 14 rows cut into it. Each row was 3 mm in width and held 10 kernels within its entire length. This enabled radiographs to be made of three different samples of 40 kernels each at each exposure.

Microphotometer

The radiographs were scanned by a Leeds and Northrup Model DB-94 Microphotometer which recorded cracks in the individual kernels as the radiographs were driven at a uniform speed past the scanning beam.

RESULTS AND DISCUSSION

X Ray Radiographs

In Plate IV are shown several x ray radiographs. Each radiograph contains three different wheat samples, there being four rows of each sample. The results of a visual inspection of the radiographs for the Soft White Western wheat, sample 67-6005, are shown in Table 2. This table indicates, for example, that 40 kernels of the control sample contained 10 observable cracks, while an identical number of kernels of the E sample contained 123 observable cracks.

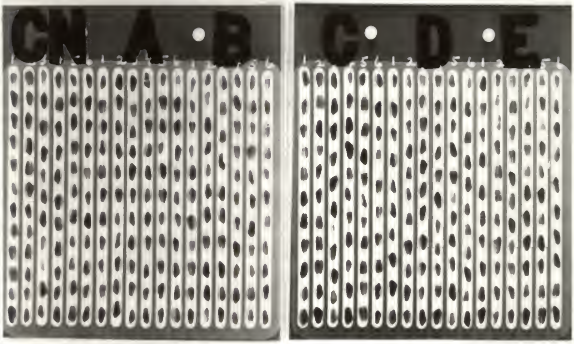
Microphotometer Tracings

In Plate V are shown the microphotometer tracings of several kernels of two of the 67-6005 samples. Each large peak represents one wheat kernel while the smaller peaks within the much larger kernel peaks correspond to cracks as detected by the microphotometer scanning light beam. In comparing the tracings of the undamaged or slightly damaged samples with those of the more severely damaged samples, the

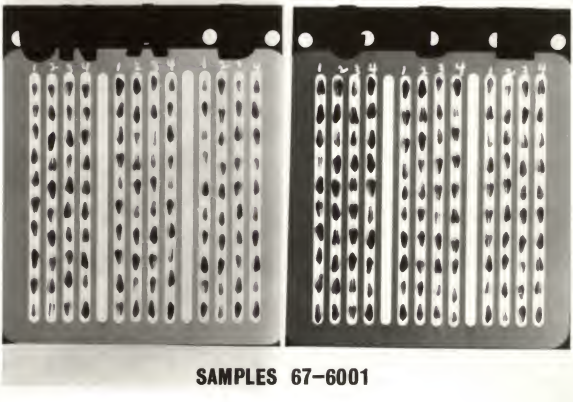
EXPLANATION OF PLATE IV

X ray radiographs of Samples 67-6001 Control through E and Samples 67-6005 Control through E.

PLATE IV



SAMPLES 67–6001



SAMPLES 67–6001

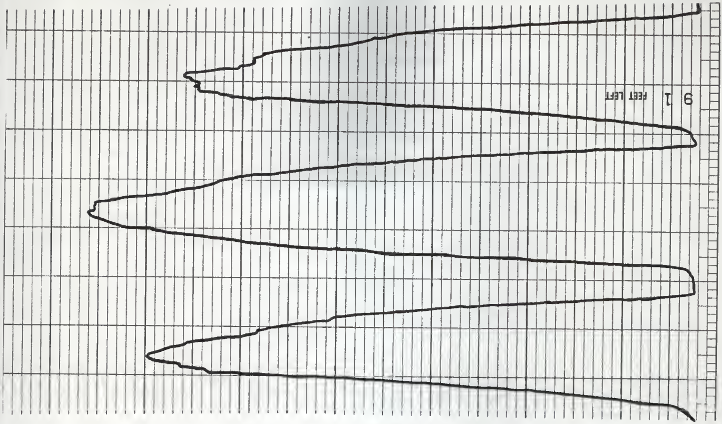
Table 2. The Results of a Visual Inspection of the Radiographs of Samples 67-6005 Control through E.

Samples	Number of Kernels	Number of Cracks Observed
67-6005 Control	40	10
67-6005 A	40	11
67-6005 B	40	11
67-6005 C	40	111
67-6005 D	40	147
67-6005 E	40	123

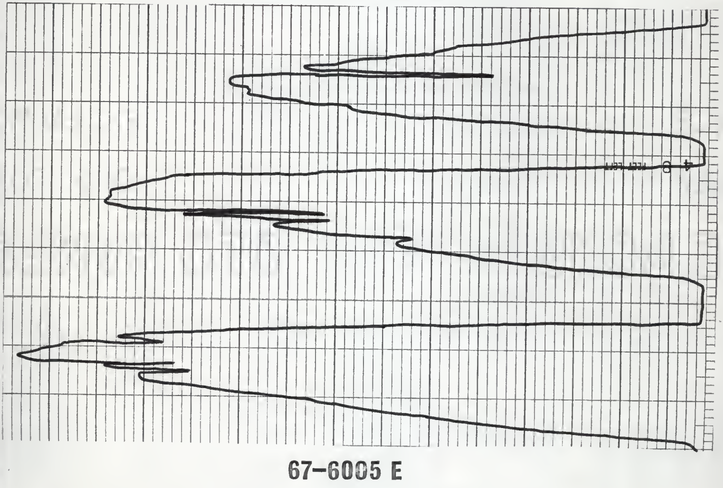
EXPLANATION OF PLATE V

Microphotometer tracings of three kernels of Sample 67-6005 Control (undamaged) and three kernels of Sample 67-6005 E (severely damaged).

PLATE V



67-6005 CONTROL



67-6005 E

numerous cracks of the highly damaged samples appear as irregularities in the kernel tracing while the slightly damaged or undamaged kernels exhibit relatively smooth kernel peaks.

Equilibrium Vapor Pressure and Relative Humidity Graphs

In Plates VI and VII are shown the equilibrium vapor pressure curves of the 67-6001 and 67-6005 sample series, respectively, over a temperature range of approximately 20°-50°C. As expected, these graphs indicate an increase in equilibrium vapor pressure as the sample's environmental temperature is raised. Also to be expected are the greater equilibrium vapor pressures for samples of higher initial moisture content. A somewhat close correlation can be observed between moisture content and equilibrium vapor pressure; the relationship being that the greater a sample's initial moisture content the greater will be its equilibrium vapor pressure at a given temperature. With variations in equilibrium vapor pressure apparently arising as a result of sample moisture content, the wheat samples, damaged to varying degrees, were then brought to a nearly uniform moisture content. With the variable moisture content among samples eliminated, it was thought that relationships between equilibrium vapor pressure and extent of damage, if any existed, could be

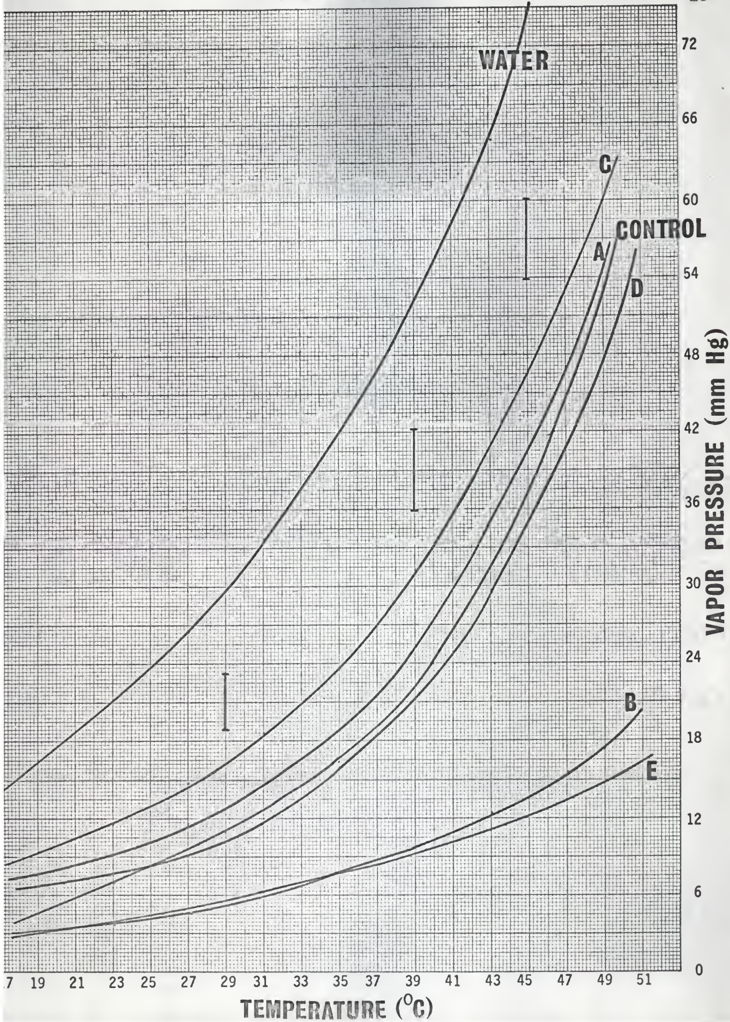
EXPLANATION OF PLATE VI

Equilibrium vapor pressure versus temperature curves of Samples 67-6001 Control through E with moisture contents (wet basis) of:

Control ------------- 11.88%
A ------------- 12.52%
B ------------- 7.80%
C ------------- 12.77%
D ------------- 11.59%
E ------------- 6.92%

Error bars in this and subsequent graphs indicate experimental uncertainties in various temperature ranges.

PLATE VI

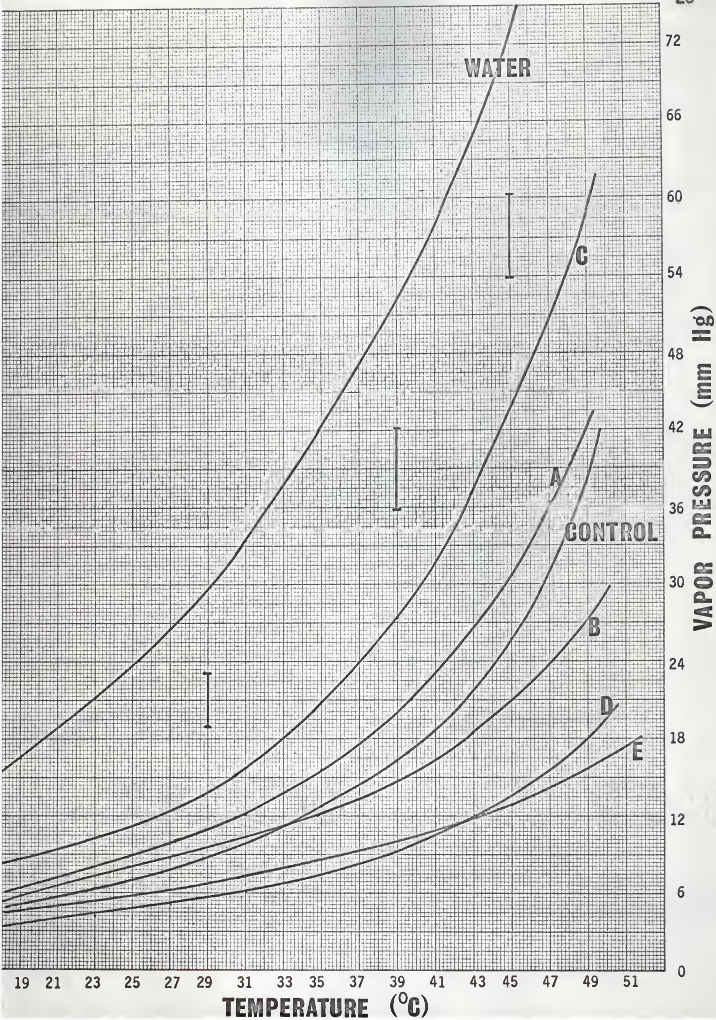

WATER
C
CONTROL
A
D
B
E
72
66
60
54
48
42
36
30
24
18
12
6
0
VAPOR PRESSURE (mm Hg)
7
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
TEMPERATURE (°C)

EXPLANATION OF PLATE VII

Equilibrium vapor pressure versus temperature curves of Samples 67-6005 Control through E with moisture contents of:

Control ------------- 10.29%
A ------------- 10.60%
B ------------- 8.75%
C ------------- 12.96%
D ------------- 7.39%
E ------------- 7.45%

PLATE VII


WATER
C
A
CONTROL
B
D
E
VAPOR PRESSURE (mm Hg)
72
66
60
54
48
42
36
30
24
18
12
6
0
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
TEMPERATURE (°C)

observed and analyzed.

In Plate VIII are shown the relative humidity curves of four samples of the 67-6005 series. Plotted are the curves for the undamaged control sample, the very slightly damaged A sample, and the severely damaged D and E samples. The curves seem to indicate that over this particular temperature range the more damaged samples have a somewhat higher equilibrium vapor pressure than the undamaged and slightly damaged samples. These differences in equilibrium vapor pressure at various temperatures among the samples most likely cannot be attributed to variations in sample moisture content, since all samples had essentially the same initial moisture content. Also, it can be observed that at temperatures above approximately 60°C the relative humidity values of all increase less rapidly than at lower temperatures. These results would seem to agree with the assumption that at lower temperatures free water is distilled off quite readily while, as higher temperatures are realized, it becomes increasingly difficult to remove the more tightly bound water.

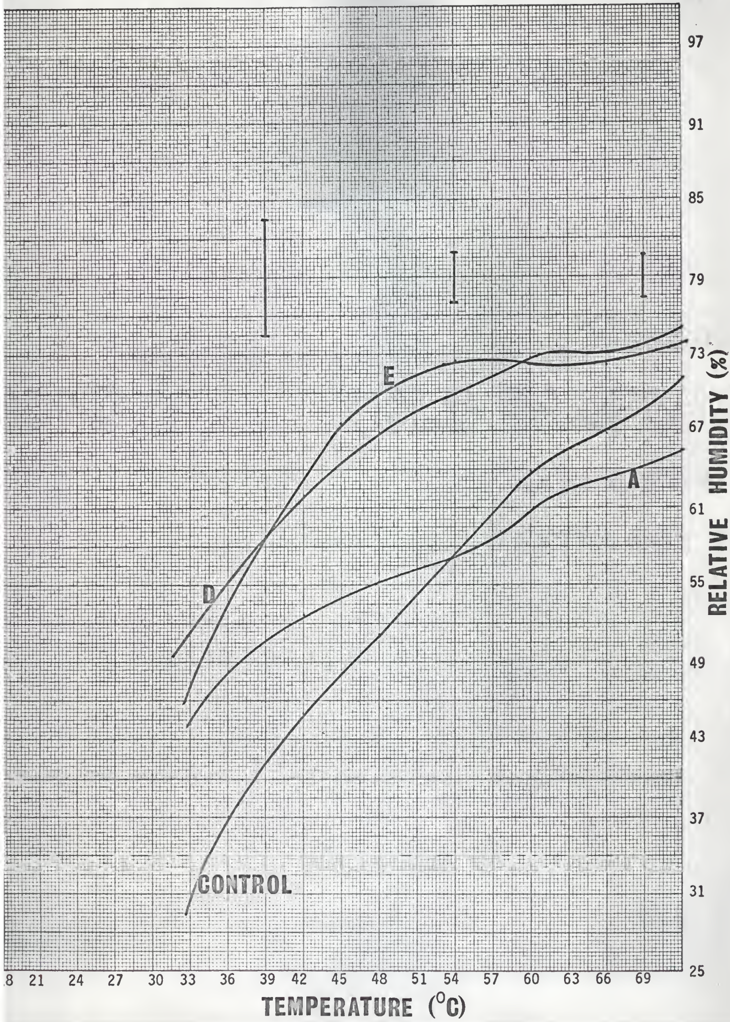
In Plate IX are shown the relative humidity curves for members of the 67-6001 series which have all been brought to a moisture content of approximately 12%. The curves indicate that at lower temperatures the control or undamaged sample has a lower equilibrium vapor pressure than all damaged samples, lower even than those with slight heat damage. This would

EXPLANATION OF PLATE VIII

Relative humidity versus temperature curves of four members of 67-6005 series with moisture contents of:

Control ------------- 14.13%
A ------------- 14.02%
D ------------- 14.46%
E ------------- 13.80%

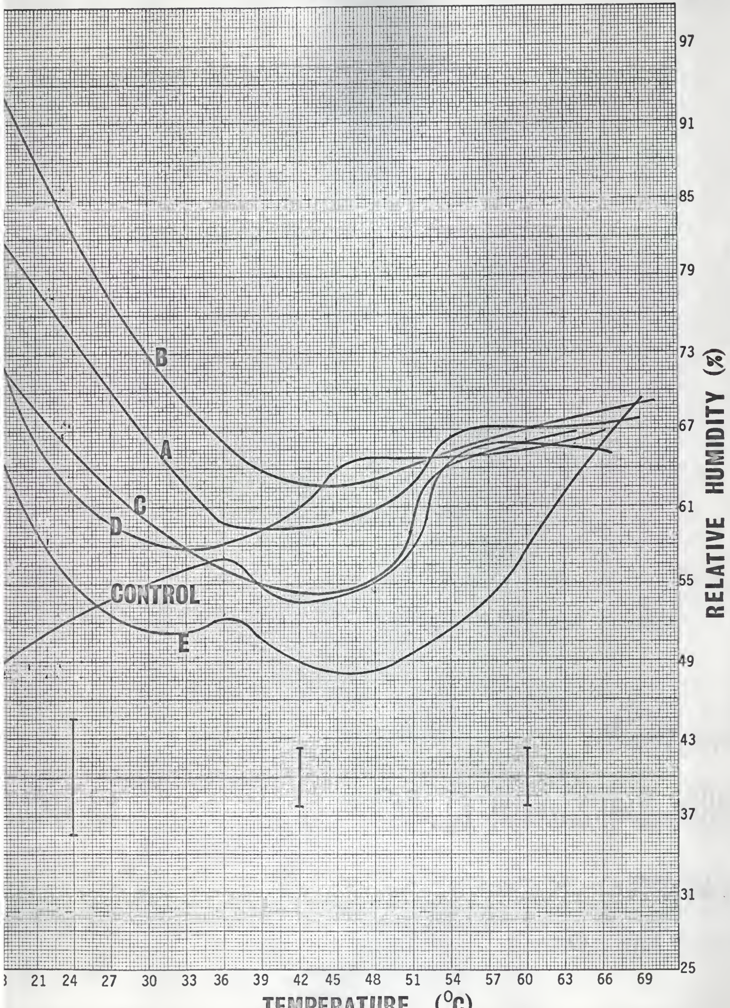
PLATE VIII


97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
.8
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)
E
D
A
CONTROL

EXPLANATION OF PLATE IX

Relative humidity versus temperature curves for Samples 67-6001 Control, A, B, C, D and E which have all been brought to a moisture content of approximately 12%.

PLATE IX


B
A
C
D
CONTROL
E
97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)

seem to indicate that perhaps previous treatment undergone by a wheat kernel somehow affects the moisture retention properties of that wheat kernel. In Plate X are shown the relative humidity curves of three samples of the 67-6001 series. The primed samples represent the tempered specimens while the unprimed samples represent the original, untempered wheat specimens. All samples tested had essentially the same initial moisture content. All curves possess the same general shape, however, the samples retempered to a moisture content of approximately 12% display a higher equilibrium vapor pressure over much of the temperature range covered than the original untempered samples. This would seem to indicate that the moisture added in tempering is differently held than that naturally present.

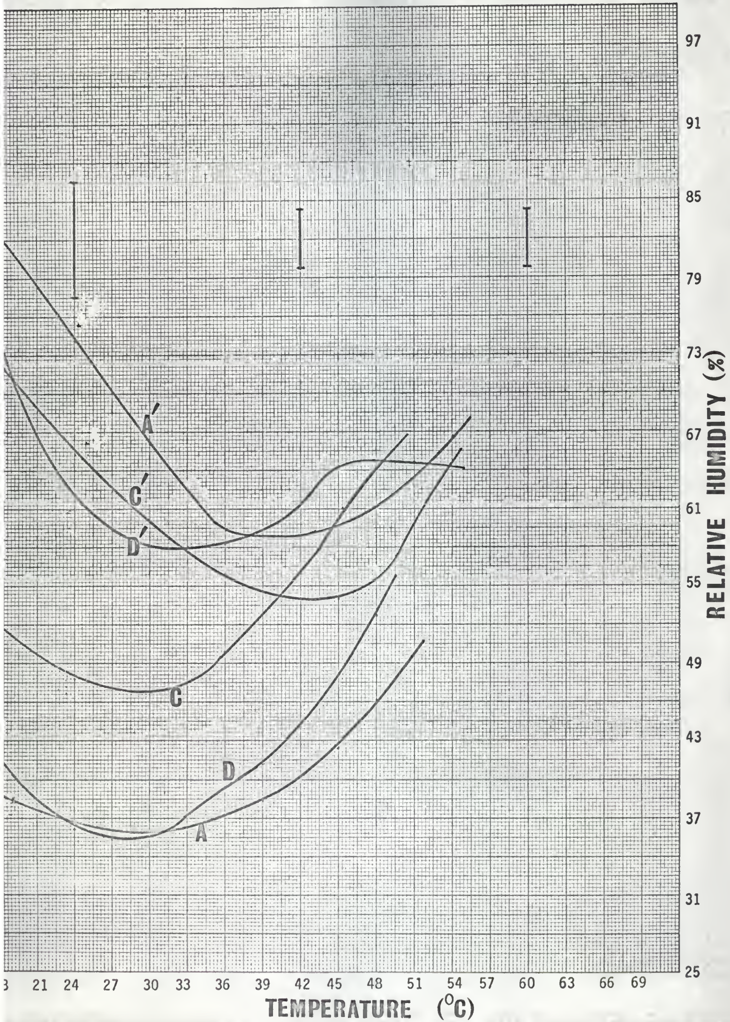
In Plate XI are shown the relative humidity curves of two molded samples of the 67-6001 series, a Hard Red Winter wheat, and two molded samples of the 67-6005 series, a Soft White Western wheat. The two Soft White Western wheat samples have, over most of the temperature range covered, consistently greater equilibrium vapor pressures than the corresponding samples of the Hard Red Winter wheat. Since the equilibrium vapor pressure at a given temperature is proportional to the extent of mold infestation, these experimental results would seem to indicate that the Soft White Western wheat samples were more thoroughly mold infested. Consequently, since both sample series were molded and tested under similar

EXPLANATION OF PLATE X

Relative humidity versus temperature curves of three original, untempered samples (unprimed) of the 67-6001 series and three samples of the same series which had been tempered to a moisture content of approximately 12% (primed). The moisture contents of the three original, untempered samples were:

A ------------- 12.52%
C ------------- 12.77%
D ------------- 11.59%

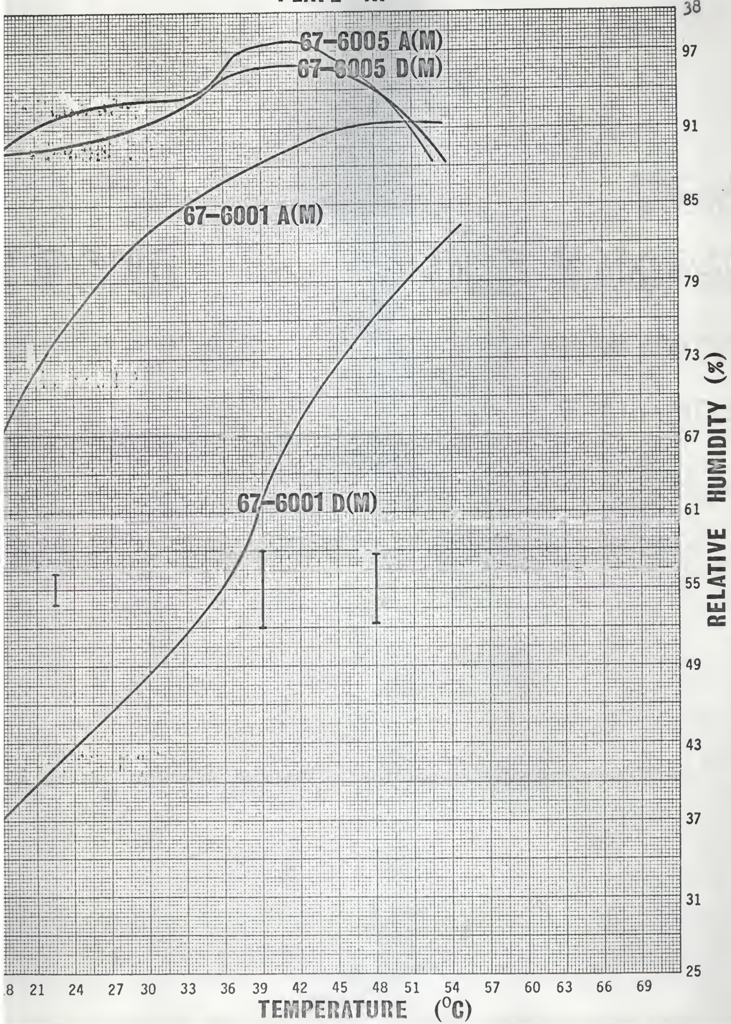
PLATE X


A′
C′
D′
C
D
A
97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)

EXPLANATION OF PLATE XI

Relative humidity versus temperature curves of the A and D samples of both the 67-6001 series and the 67-6005 which have been molded and tested under similar conditions.

PLATE XI



67-6005 A(M)
67-6005 D(M)
67-6001 A(M)
67-6001 D(M)
38
97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
.8
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)

conditions, it would seem that the Soft White Western wheat was more susceptible to mold attack and proliferation than the Hard Red Winter wheat. These results more clearly verify this assumption stated previously by Papavizas and Christensen (7). Shown in Plate XII are the relative humidity curves of four members of the 67-6005 series; two samples were undamaged or only slightly damaged and two samples were extensively damaged. These samples were treated in a manner similar to that of the molded samples, the one difference being that these samples were not directly inoculated with a mold. The samples were kept in equilibrium with a relative humidity of 85% at 30°C for a period of about two weeks. At the end of this period mold growth had established itself in the samples, however, not nearly to the extent as in the samples which had been directly inoculated. The relative humidity values of the more severely damaged samples consistently appear to be greater than those of the less extensively and undamaged samples. These results would be in agreement with the conclusion of Milner and Geddes (1946) that more severely damaged wheat has a greater susceptibility to mold infestation than lesser damaged wheat under comparable conditions.

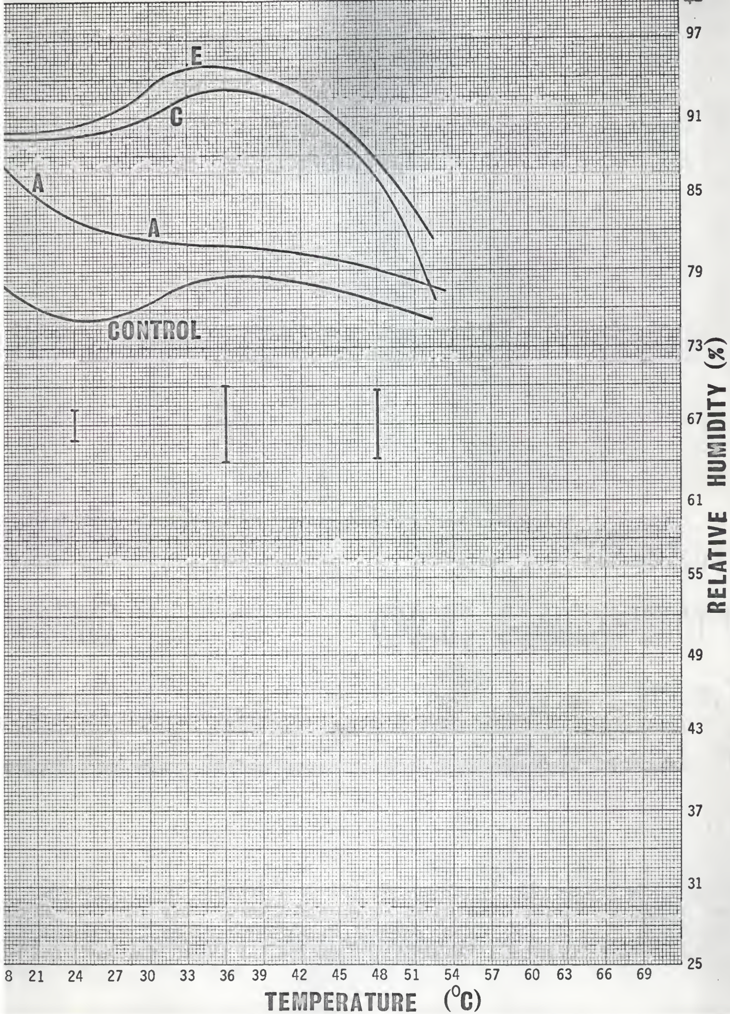
In Plate XIII are shown the relative humidity curves of four samples of the 67-6001 series, two of which had been molded, the other two were of nearly the same initial moisture content and unmolded. As before, in comparing the equilibrium vapor pressures of the unmolded samples of nearly equal initial

EXPLANATION OF PLATE XII

Relative humidity versus temperature curves of four samples in 67-6005 series which were not directly inoculated with mold but were otherwise treated in the same manner as the molded samples. Initial moisture contents for these samples before treatment were:

Control ------------- 10.29%
A ------------- 10.59%
C ------------- 12.96%
E ------------- 7.45%

PLATE XII

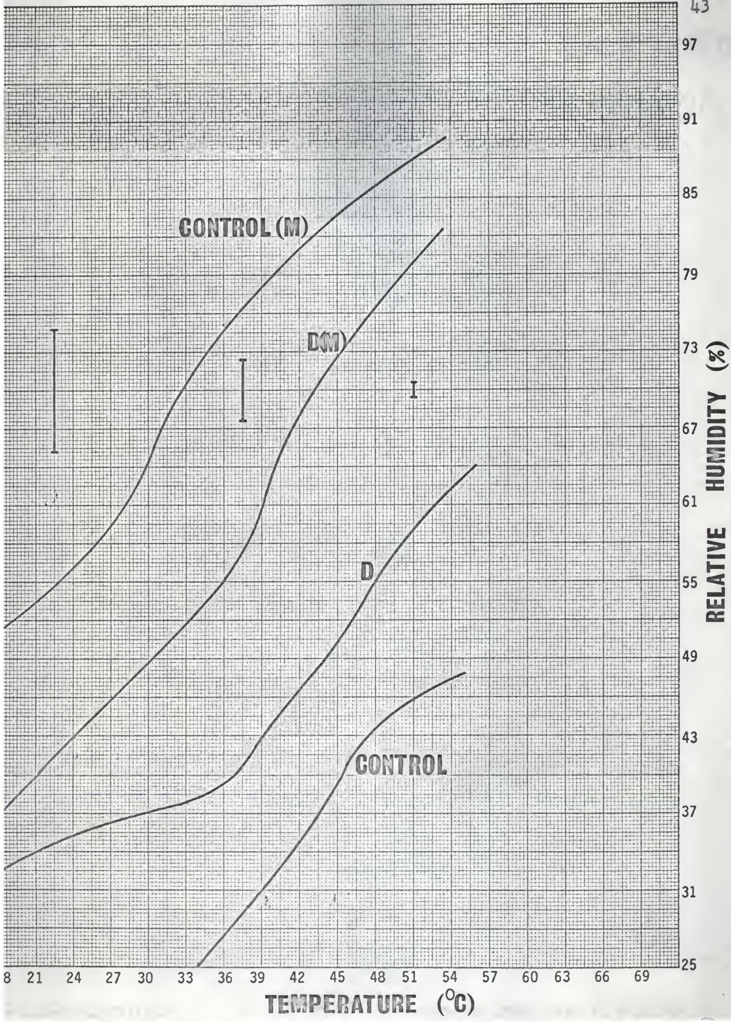

E
C
A
A
CONTROL
97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
8
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)

EXPLANATION OF PLATE XIII

Relative humidity versus temperature curves of four samples of the 67-6001 series, two of which had been molded (M), the other two samples were unmolded and of nearly the same initial moisture content, i.e.,

Control	11.88%
D	11.59%

PLATE XIII


CONTROL (M)
D(M)
D
CONTROL
97
91
85
79
73
67
61
55
49
43
37
31
25
RELATIVE HUMIDITY (%)
8
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
TEMPERATURE (°C)

moisture contents, the severely damaged D sample exhibits greater equilibrium vapor pressures over all temperatures covered than the undamaged control sample. Also, the molded samples exhibit greater equilibrium vapor pressures than the unmolded samples, which is to be expected since during respiration water is produced by the mold growth. The presence of mold appears to increase the equilibrium vapor pressure of the wheat sample a nearly uniform amount at all temperatures to which the samples were subjected.

CONCLUSIONS

Visual inspection of x ray radiographs was an effective method in the analysis of grain damage. There was a close relationship between severity of grain damage treatment and the number of visible cracks, with the more severely damaged samples having greater numbers of observable cracks than lesser damaged wheat samples. The microphotometer technique also could be effectively used as a tool in grain damage analysis, although the feasibility of its use on a large scale would have to be evaluated for economic practicability.

From the experimental results previously presented it seems that under similar conditions a comparison of equilibrium vapor pressures of undamaged and severely damaged wheat samples would show the more damaged wheat sample to have the higher equilibrium vapor pressure. Similarly, the more severely damaged wheat sample would be expected to be more susceptible to mold infestation and also the softer the wheat the greater would be its susceptibility to infestation. Water added to wheat during tempering was found to be held by the wheat kernel differently than that naturally present. This experimental procedure could also be applied to the detection of damage to wheat by wetting such as rain or flood.

APPENDIX

Experimental Error Determinations

The error bars included in all previous graphs can be interpreted as the experimental reproducibility of the recorded vapor pressures within various temperature ranges. Water was used in the calibration of both sets of apparatus and it was found that the water vapor sensing devices, both the electrolytic sensor and the strain gauge sensor, exhibited different sensitivities at various temperatures. The sensitivity of the vapor pressure detector, and thus of the apparatus, was determined by the ability of the apparatus to reproduce experimental results using water as a standard. In a temperature range of very high reproducibility the apparatus could be described as highly sensitive, while the opposite could be said of a temperature range in which the apparatus was inconsistent in its vapor pressure values in comparable water test runs.

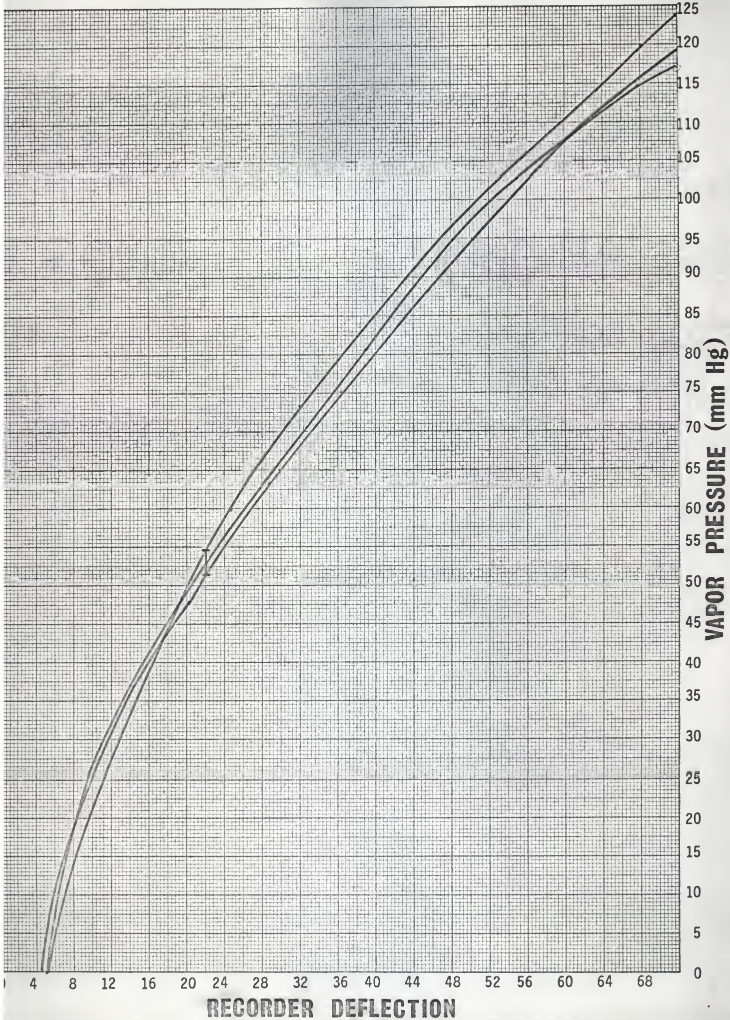
In Plate XIV are shown the results of three different water runs over a temperature range of approximately 18°-60°C.

These three water runs were used in the calibration of Apparatus I for the test runs of a particular series of wheat samples and were made alternately with the wheat test runs. Vapor pressure is plotted against recorder deflection and from these results differences in recorder deflection for a particular vapor pressure can be observed. For example, at 40°C water has a vapor pressure of 55.3 mm of Hg and from the three curves it can be seen that at this temperature there is an experimental error of approximately ± 1.4 mm of Hg. Error bars were determined for three approximately evenly spaced temperatures for all data recorded. For each set of wheat samples tested, several water runs were made intermittently among the wheat tests so that many comparisons could be made of the apparatus' behavior from one test run to the next.

EXPLANATION OF PLATE XIV

Vapor pressure versus recorder deflection curves for three water runs on Apparatus I. From the variation of these curves from test run to test run, the experimental uncertainties (error bars) in wheat tests were determined for different temperature ranges.

PLATE XIV


0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
RECORDER DEFLECTION
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
VAPOR PRESSURE (mm Hg)

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ANALYSIS OF MOISTURE CONTENT AND HEAT DAMAGE OF WHEAT USING PHYSICAL TECHNIQUES

by

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AN ABSTRACT OF A MASTER'S THESIS

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Molded and unmolded wheat samples which had been crack damaged to varying degrees by heat and in some cases water soaking treatment were placed in a small vacuum chamber and subjected to various environmental temperatures in order to determine relationships between extent of damage and equilibrium water vapor pressure. Comparisons were also made between equilibrium vapor pressures of tempered and untempered wheat samples of the same per cent moisture content. All experiments were carried out within a temperature range of approximately 20°- 60°C.

X ray radiographs made of the damaged and undamaged samples were visually scanned for crack damage and also scanned by a microphotometer light beam which permitted graphical tracings of individual kernels to be made. It was found that both visual scanning and the microphotometer technique could be employed as useful tools in the analysis of wheat damage.

From the vapor pressure experiments it was found that water added to wheat in tempering was released upon heating more readily than water naturally present in the wheat kernel. Experimental results also indicated that for wheat samples of the same moisture content, the more severely damaged samples had greater equilibrium vapor pressures than the undamaged and slightly damaged samples at corresponding temperatures. It was verified that the more severely wheat was damaged, the greater was its susceptibility to mold infestation. A soft wheat variety was found to be more susceptible to mold infestation than a hard wheat sample.