Internal Damage of Wheat Kernels by Successive Wetting and Drying Cycles[1]

D. S. CHUNG and H. H. CONVERSE[2], Department of Agricultural Engineering, Kansas State University, Manhattan

ABSTRACT

Effects of wetting and drying cycles on the extent of internal damage of wheat and related effect on kernel breaking strength were evaluated with two varieties of HRW wheat, Ottawa and Scout. A substantial increase in internal cracks or fissures in kernels owing to repeated wetting and drying cycles was observed. Radiographical examination of internal damage of wheat kernels showed that treatments caused only radial cracks. Studies showed that Scout wheat is more susceptible to internal damage from treatment than Ottawa wheat. When the number of cycles was increased, kernels with multiple internal cracks increased while those with single cracks decreased. Increased drying temperature tended to increase internal damage to wheat kernels. However, effects of drying temperature were less pronounced than the number of the successive cycle. Examination indicated that the average breaking strength decreased linearly with increased internal damage. Frequency distribution of the breaking strength of wheat kernels appeared to be normal. An index for predicting or describing susceptibility to breakage of wheat kernels was defined as the reduction in damage resistance owing to internal cracks. A linear relation between the index and percent internal damage was obtained.

[1]Contribution No. 154, Department of Agricultural Engineering, Kansas State Agricultural Experiment Station, Manhattan.

[2]Respectively: Assistant Professor, Department of Agricultural Engineering, Kansas State University, and Agricultural Engineer, Handling and Facilities Research Branch, TFRD, ARS, USDA, Manhattan, Kansas.

During recent years, grain damage has received increased attention from researchers and grain processing industries because of significant economic loss in domestic and foreign trades. Proper control of the harvesting, handling, processing, and drying operations is necessary to minimize this damage.

Grain damage can be classified into two categories–external and internal. Both damages might result from either physical (structural) or physiological change in grains in the field or during drying, storage, and handling. Physical change often enhances certain physiological changes which further deteriorate grain. External damage (physical), commonly known as mechanical damage, is caused mostly by combines and other handling equipment, whereas internal damage (physical) is caused mainly by environmental changes.

Some grains suffer considerable internal damage (cracks and fissures) in the field prior to harvesting. The damage results from stresses induced by moisture gradient and possibly temperature gradient within the kernel. Grain in the field is indeed subjected to many wetting and drying cycles and much temperature variation. Such damage may not only lower the quality of the grain but also be detrimental during future handling and storage.

In spite of the economic significance of internal damage, only limited studies on its cause and extent have been reported. Sufficient information on the extent of such damage both in the field prior to harvest and by harvesting and handling equipment is needed to develop improved methods and equipment for handling grains with minimum damage.

This investigation was designed to study the effects of drying and wetting cycles on the actual extent of internal damage of wheat kernels under temperature variation, and the susceptibility to breakage of internally damaged wheat grains.

REVIEW OF LITERATURE

Milner and co-workers (1) first reported the examination of cereal grains by X-ray for checking insect infestation. Hogan and co-workers (2) have used X-ray for the rapid examination of rough rice for cracks, checks, insect damage, and immature seed.

The radiographical evidence of internal fissures in wheat owing to weathering, wetting, and drying was shown by Milner and Shellenberger (3). However, in their work, no attempt was made to evaluate the actual extent of internal cracks in wheat kernels, and only limited data regarding the strength of kernels associated with internal cracks were reported. The effect of internal cracks in grains on adsorption and desorption of water vapor by grains was discussed by Chung and Pfost (4), and Chung and Converse (5) studied several varieties of HRW wheat from 1966 and 1967 crops harvested by hand and combined at various locations to check the effects of variety, location, method of harvesting (hand and combine), year, and interactions of factors on the extent of internal damage. Although significant effects of variety and method of harvesting on internal damage were observed, the effects of year and location were much more pronounced. Thus, cracks in wheat result mainly from environmental change. The relation between environmental factors and physical conditions of grain causing fissures in the rice kernel has been studied by Kunze and Hall (6). Foster and Thompson (7) investigated the effect of artificial drying on stress-crack development and breakage in shelled corn.

Bilanski (8) investigated the force and energy required to cause grain damage under loading conditions similar to those of actual harvesting and processing. The size, moisture content, and orientation of the grain influenced its breaking strength. Basic mechanical and rheological properties of bean, corn, and wheat kernels were also determined by Zoerb and Hall (9). Moisture content was found to have the greatest influence on the strength properties of the grain.

In reviewing literature only limited data on the conditions and causes of internal damage to cereal grains are available. Furthermore, the relation between the incidence of cracks and actual breaking strength of wheat kernels has not been reported.

MATERIALS AND METHODS

The investigation on internal damage of wheat by successive wetting and drying was conducted with Ottawa and Scout wheats (1966 crops), freshly harvested at 10.0 and 10.5% initial moisture contents, respectively, from the field at Manhattan, Kans. The samples of Ottawa and Scout were immersed in a water bath at 100°F. until approximately 20% moisture content was obtained. The wetted sample was spread out on filter paper to remove surface moisture and then allowed to temper for 40 min. Moisture content of the wetted sample was evaluated by the two-stage oven method.

The drying phase of the tests was conducted by placing a 50-g. wetted sample in a wire basket suspended from a torsion balance on the top of a mechanical convection oven. Drying temperatures studied were 100°, 120°, 140°, 160°, and 180°F. Samples were dried to approximately 12% moisture content, then cooled in a desiccator to room temperature. The moisture content of the dried sample was then evaluated. These procedures were repeated for three successive drying cycles. A sample at the end of each drying cycle was examined for internal damage. Each treatment was replicated.

The evaluation of internal damage was made radiographically using a commercial X-ray grain inspection unit, rated at 25 KV peak and 5 ma. Exposures were made on industrial X-ray film. To evaluate percentage of internal damage, 3 random samples of 100 kernels for each treatment combination were examined radiographically and classified into two categories–single crack and multiple crack. The original samples for Ottawa and Scout wheat had 8 and 5% single cracks, respectively.

Data were obtained on the breaking strength of individual kernels after each drying cycle, using a Dillon Model LW compression tester. A single kernel was placed in the flat position (crease down) and the compressive load was applied gradually. A random sample of ten kernels with known internal damage from each treated and untreated sample was tested. Average moisture contents of samples at the time of evaluating breaking strengths were 9.5% for Ottawa wheat and 10.0% for Scout.

RESULTS AND DISCUSSION

Two varieties (Ottawa and Scout), three successive cycles, and five drying temperature levels were studied. Average moisture contents after wetting were 20.1% for Ottawa and 19.8% for Scout. Average moisture contents after drying were 12.3% for Ottawa and 12.0% for Scout. Portions of the radiographs of treated and untreated Ottawa wheat kernels (the third cycle dried at 180°F.) are shown in Figs. 1 and 2, respectively. Comparison of the two photographs shows a substantial increase in internal cracks in kernels owing to the treatment.

The percentages of kernels with single cracks, multiple cracks, and with either single or multiple cracks (total) are tabulated in Table I for Ottawa wheat and in Table II for Scout wheat. The ranges of total cracks for Ottawa wheat were 35 to 57% after the first drying cycle; 54 to 76% after the second cycle; and 74 to 91% after the third cycle. For Scout wheat, 44 to 68% of the kernels showed cracks after the first drying cycle; 70 to 87% after the second cycle; and 84 to 94% after the third cycle.

A 2×3×5 factorial design was used to study the effects of main factors—variety, wetting and drying cycle, and drying temperature—and their interactions on extent of internal damage. The analyses showed highly significant ($\alpha = 0.01$) effects of the three main factors on the formation of multiple cracks and on total internal damage. On single cracks only, the effects of drying temperature and wetting and drying cycle were significant. There were no significant interactions among the main factors studied.

More internal damage was observed in Scout than in Ottawa wheat. When cycle number was increased, multiple cracked kernels increased but single cracked kernels

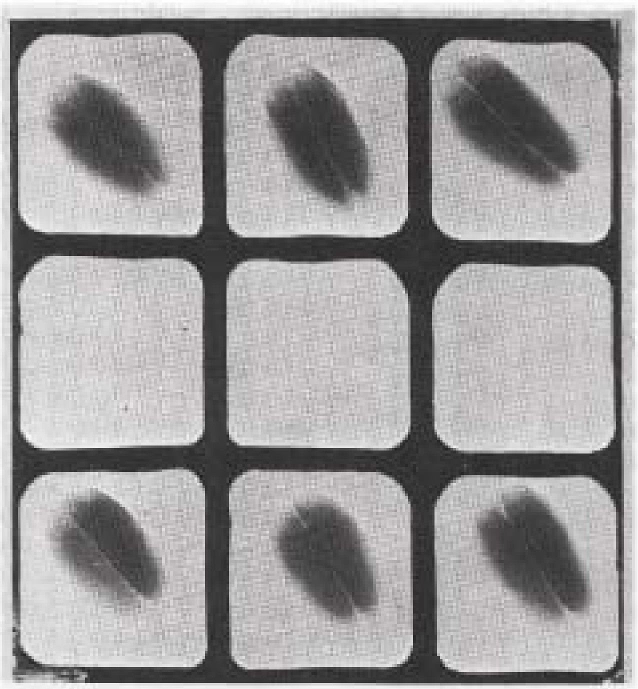

Fig. 1. Portion of radiograph of untreated Ottawa wheat kernels (8% damage).

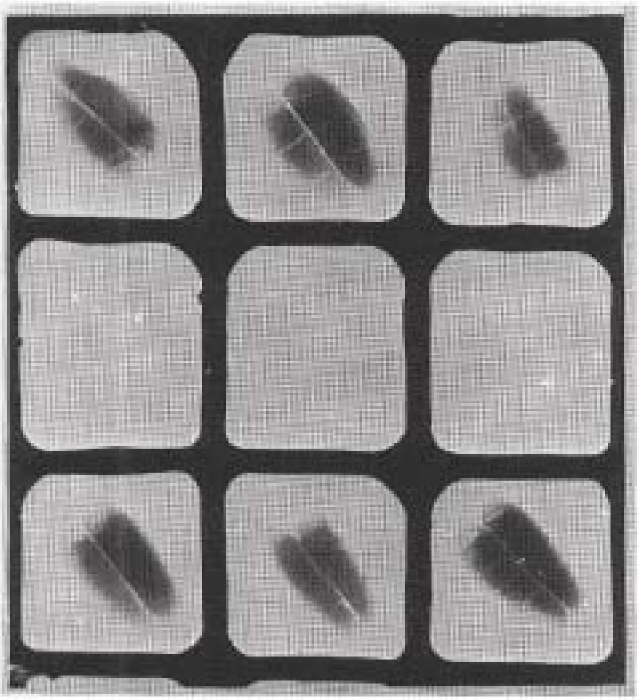

Fig. 2. Portion of radiograph of treated Ottawa wheat kernels (third cycle dried at 180°F. and 91% damage).

decreased. The first wetting and drying cycle caused the greatest increase in total cracks. In the first cycle, 4 to 7 times more cracks appeared in treated than in untreated kernels of Ottawa wheat, 9 to 14 times more in Scout wheat; the second cycle, 7 to 9 times more in Ottawa, 14 to 17 times more in Scout; the third cycle, 10 to 11 times more in Ottawa, and 17 to 19 times more in Scout. Scout wheat appears more susceptible to internal damage from treatment than Ottawa wheat. Also, higher drying temperature tended to increase internal damage. However, the effect of drying temperature was less pronounced than that of the successive cycle.

Breaking strengths of Ottawa and Scout wheat kernels at crease down, with internal damages known from radiographs, were evaluated to study the susceptibility to breakage of internally damaged kernels. Breaking strengths obtained by averaging values from all kernels tested for a given treatment combination are tabulated along with corresponding internal damage of wheat samples in Table I for Ottawa wheat and Table II for Scout wheat. The upper and lower limits of 95% confidence interval on the breaking strength also are given in Tables I and II. Average breaking strengths of wheat kernels for various treatment combinations are plotted in Fig. 3. For a given cycle, the average breaking strength decreased with increased drying temperature. The average breaking strength decreased with increasing number of cycles.

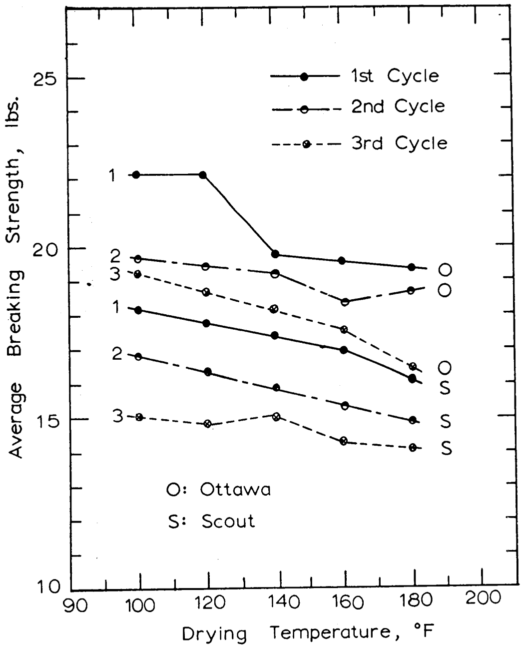

Fig. 3. Effects of drying temperature and number of cycle on average breaking strength of Ottawa and Scout wheat kernels.

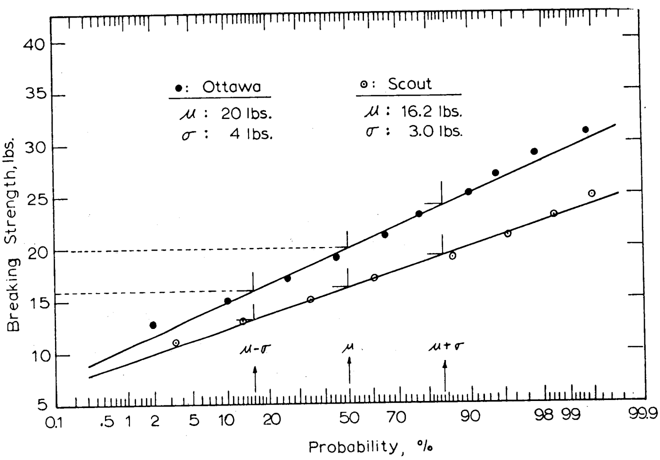

Fig. 4. Cumulative frequency distributions of breaking strength of Ottawa and Scout wheat kernels in normal probability graph.

TABLE I. RESULTS OF INTERNAL DAMAGE AND BREAKING STRENGTH OF OTTAWA WHEAT

Drying Temperature °F.	Cycle	Single[a] Cracks %	Multiple[a] Cracks %	Total Cracks %	Breaking[b] Strength lb.	CI 95[c] Upper limit lb.	CI 95[c] Lower limit lb.
	No treatment	8	0	8	25.7	27.9	23.5
100	1	27	12	39	22.1	24.8	19.4
	2	24	38	62	19.6	22.1	17.2
	3	17	60	77	19.2	21.1	17.3
120	1	26	9	35	22.1	24.6	19.6
	2	22	32	54	19.4	22.2	16.5
	3	20	54	74	18.6	20.3	17.0
140	1	28	19	47	19.7	22.5	16.9
	2	17	56	73	19.2	22.0	16.5
	3	10	70	80	18.2	20.7	15.7
160	1	23	33	56	19.6	22.9	16.4
	2	22	54	76	18.4	20.1	16.7
	3	15	66	81	17.5	19.3	15.8
180	1	24	33	57	19.3	22.3	16.4
	2	16	46	62	18.7	21.6	15.8
	3	8	83	91	16.2	18.0	14.3

[a]Average values of two replications.

[b]Average values of ten kernels.

[c]95% Confidence interval on breaking strength.

Comparison of average breaking strength indicated a significant difference between Ottawa and Scout wheat kernels. Ottawa wheat kernels were about 2 to 3 lb. stronger than Scout wheat kernels at the same degree of internal damage. The average breaking strengths of untreated wheat kernels were 25.7 lb. for Ottawa and 21.6 lb. for Scout, with internal damages of 8 and 5%, respectively. Even at mild treatment, the damage resistance force was considerably dissipated owing to the formation of cracks in kernels. For example, in the third cycle dried with 100°F. air temperature, 25 and 30.5% of original breaking strengths of Ottawa and Scout were dissipated owing to the treatment.

The breaking strengths of individual wheat kernels followed a normal distribution. When the distribution is normal, plotting the cumulative percent frequency against the corresponding values of the breaking strength on a probability graph yields a straight line as shown in Fig. 4. From such a graph the mean and standard deviation can be obtained. Figure 4 shows that the mean value of breaking strength for all Ottawa and Scout kernels tested was 20 and 16.2 lb., respectively. The corresponding calculated values were 19.9 and 16.2 lb., respectively. The standard deviations read from Fig. 4 were 4 lb. for Ottawa wheat

TABLE II. RESULTS OF INTERNAL DAMAGE AND BREAKING STRENGTH OF SCOUT WHEAT

Drying Temperature °F.	Cycle	Single[a] Cracks %	Multiple[a] Cracks %	Total Cracks %	Breaking[b] Strength lb.	CI 95[c] Upper limit lb.	CI 95[c] Lower limit lb.
	No treatment	5	0	5	21.6	23.3	19.9
100	1	30	14	44	18.2	19.3	17.1
	2	19	51	70	16.8	19.3	14.3
	3	20	64	84	15.0	18.1	14.7
120	1	34	22	56	17.8	19.4	16.2
	2	22	49	71	16.4	17.2	14.6
	3	20	67	87	14.8	16.6	13.1
140	1	27	37	64	17.4	18.7	16.2
	2	20	59	79	15.9	16.2	14.3
	3	13	73	86	15.0	16.3	13.7
160	1	28	40	68	17.0	18.4	15.6
	2	15	72	87	15.2	16.7	13.4
	3	7	85	92	14.3	15.6	12.9
180	1	25	38	63	17.4	18.9	15.9
	2	16	68	84	14.9	16.2	13.6
	3	13	81	94	14.0	15.2	12.9

[a]Average values of two replications.

[b]Average values of ten kernels.

[c]95% Confidence interval on breaking strength.

kernels and 3 lb. for Scout kernels. The corresponding calculated values were Ottawa 3.8 lb. and Scout 2.9 lb.

The effect of internal damage on the breaking strength of Ottawa and Scout wheat kernels is shown in Fig. 5. As expected, the average breaking strength decreases with increased internal damage. The relation between the average breaking strength and internal damage was linear. The equations for regression lines as determined by the least squares method in Fig. 5 are:

$$Y = 25.5 - 0.098\,X \qquad \text{for Ottawa wheat} \qquad (1)$$

and

$$Y = 22.3 - 0.084\,X \qquad \text{for Scout wheat} \qquad (2)$$

where Y is the average breaking strength in pounds and X is internal damage percent.

Decrease in the average breaking strength in respect to internal damage for Ottawa wheat was slightly higher than that for Scout wheat. However, this difference was not statistically significant.

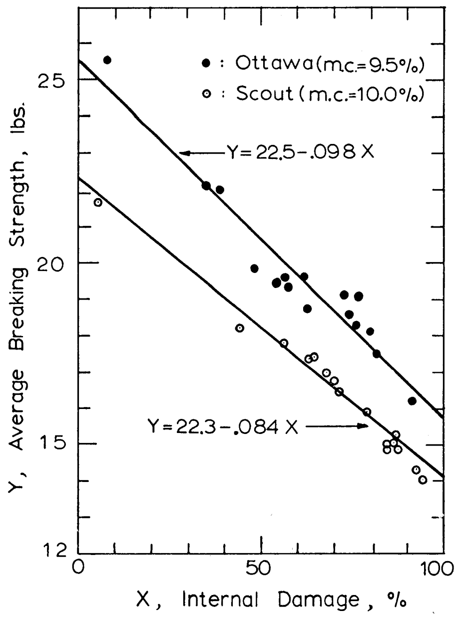

Fig. 5. Effect of internal damage on breaking strength of Ottawa and Scout wheat kernels.

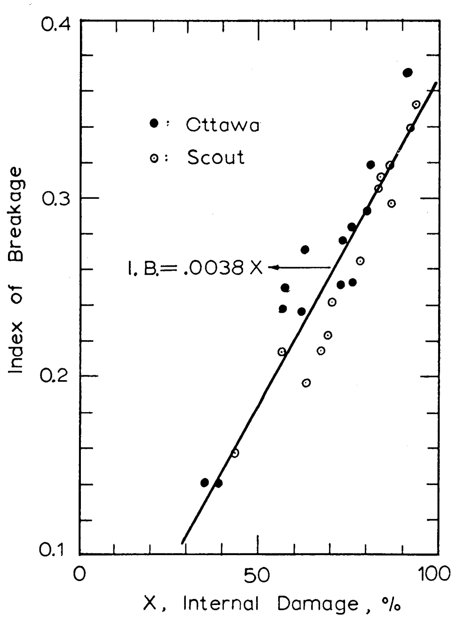

Fig. 6. Relation between index of breakage (fraction of force dissipated) and internal damage of kernels.

An index for predicting or describing susceptibility to breakage of wheat kernels is defined as:

$$\text{I.B. (Index of Breakage)} = \frac{F_o - F_t}{F_o} \qquad (3)$$

where F_o is the average breaking strength of untreated sample or internally undamaged kernels, and F_t is the average breaking strength of treated sample or internally damaged sample. Actually, this value is the damage resistance force of kernels dissipated owing to the treatment. Equation 3 can be expressed in terms of internal damage by substituting equation 1 or 2 into equation 3 which is

$$\text{I.B.} = \frac{X_o - X_t}{X_o + A/B} \qquad (4)$$

$$\text{For } X_o = 0 \quad \text{I.B.} = -(B/A)X_t \qquad (5)$$

where X_o is percent internal damage of untreated kernels (X_o = 0 for no cracks in kernels), X_t is percent internal damage of treated sample, and A and B (slope) are constants in equation 1 or 2. Index of breakage or damage resistance force dissipated for Ottawa and Scout wheat kernels is plotted against percent internal damage in Fig. 6. As indicated in equation 4 or 5, a linear relation is yielded. Thus, the higher an index for a given sample, the more susceptible it is to breakage.

The history (treatment) of grain kernels will affect the formation of cracks in kernels as shown in this and the previous investigation (5). For example, when, where, and how grains have been grown and harvested, variety of grain, storage conditions, and method of handling are factors that will affect crack formation in kernels. Equations obtained for expressing relation between average breaking strength and amount of internal damage of kernels can be useful in predicting susceptibility to breakage and in describing conditions of grains for future handling and storage.

Acknowledgment

The authors are grateful to Robert B. Mills, Department of Entomology, Kansas State University, for making available an X-ray grain inspection unit and for his technical assistance in its operation.

Literature Cited

1. MILNER, M., LEE, M. R., and KATZ, R. Application of X-ray technique to the detection of internal insect infestation of grain. J. Econ. Entomol. 43: 933 (1950).
2. HOGAN, J. T., LARKIN, R. A., and MacMASTERS, MAJEL M. X-ray and photo-micrographic examination of rice. J. Agr. Food Chem. 2(24): 1235 (1954).
3. MILNER, M., and SHELLENBERGER, J. A. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem. 30: 202 (1953).
4. CHUNG, D. S., and PFOST, H. B. Adsorption and desorption of water vapor by cereal grains and their products. III. A hypothesis for explaining the hysteresis effect. Trans. ASAE 10(4): 556 (1967).
5. CHUNG, D. S., and CONVERSE, H. H. Internal damage of wheat analyzed by radiographical examination. Proc. Symp. Grain Damage under auspices of ASAE, April 1968.
6. KUNZE, O. R., and HALL, C. W. Relative humidity changes that cause brown rice to crack. Trans. ASAE 8(3): 396 (1965).

7. FOSTER, G. H., and THOMPSON, R. A. Stress cracks and breakage in artificially dried corn. USDA, AMS-631 (1963).
8. BILANSKI, W. K. Damage resistances of seed grains. Trans. ASAE 9(3): 360 (1966).
9. ZOERB, G. C., and HALL, C. W. Some mechanical and rheological properties of grains. J. Agr. Engr. Res. 5(1): 83 (1960).

[Received May 28, 1970. Accepted August 14, 1970]