THE EFFECTS OF DRYING ON SOYBEAN GERMINATION AND SEED COAT CRACKS

THESIS

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By

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VITA

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INTRODUCTION

Drying grain has become an accepted practice in the Midwest in recent years. Many farmers and most elevators have installed equipment for drying corn. In years of wet weather, other grains including wheat and soybeans are also dried. However, most farmers avoid drying soybeans if at all possible because of the problems encountered in drying.

Mr. Bill Foster of the Landmark Seed Company at South Charleston, Ohio, was the first to point out some of the problems associated with drying soybeans. During years of rainy and damp weather, he found it necessary to accept seed soybeans above the safe storage moisture content. In order to safely store these beans, a column dryer for corn was used for drying the beans. Even though no heat was added to the drying air, he found more splits and a reduction in germination of the dried beans. These observations were confirmed by other growers in Ohio drying soybeans.

If a satisfactory method could be found to dry soybeans, there are other advantages to drying soybeans besides being able to harvest and safely store quality beans during a wet harvesting season. Studies by Lamp (1962)[1] at Wooster have shown that delaying harvest can cause large stalk and lodging losses. These losses can be as much as a bushel per

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[1] Refers to references in bibliography.

acre for an extremely delayed harvest. Shatter losses also account for large losses during harvesting, especially in very dry beans. If the beans could be harvested above the safe storage moisture level, then shatter losses of over one bushel per acre could be reduced. A satisfactory method of drying would help to ensure that timely harvesting could be practiced and thus eliminate some of the lodging and shatter losses.

Another reason for drying soybeans is that it would allow for earlier harvesting which would reduce the loss in seed viability due to field aging, which once the seed is mature, tends to weaken the viability of the seed. According to Moore (1960), field aging is dependent mainly on the moisture and temperature of the seed and the length and number of times the seed is exposed to each moisture and temperature combination. The longer the seed is exposed to both high temperature and moisture, the faster field aging takes place.

Moore also found that certain parts of the seed will age more rapidly than others due to pressure stresses. These are caused by alternate drying and wetting of the seed which produces rapid and differential swelling and shrinking of the seed coat and the embryo tissue. In view of these considerations, it would be advantageous to harvest the beans as soon after maturity as possible. But a satisfactory method of drying must be developed before early harvesting will become an acceptable practice.

Soybeans have become a very important crop in Ohio and in the United States. The soybean acreage in Ohio has risen from 940,000 acres in 1952 to over 2,300,000 acres in 1969. This increase of course means more acres need to be harvested in the same period. With a satisfactory method of drying, a producer could harvest earlier in the season and sooner after a rain, thus shortening the harvesting time.

LITERATURE REVIEW

The information available on soybean drying is very limited with most of the recent work being on the simulation of soybean drying (Alam and Shove, 1971 and Overhults, 1972). Although such publications as the Yearbook of Agriculture (1961) give the maximum drying temperature for seed soybeans as 110°F, none give the basis for these recommendations and none mention the relative humidity of the drying air as a possible factor influencing soybean quality.

Overhults indicates that "severe physical damage in the form of cracking of the beans was observed during the drying tests" but he did not investigate the causes of these cracks. He surmised the cracks were probably due to the rapid drying taking place near the surface. No information could be found on the influence of drying on soybean quality or germination.

Some studies on the effect of drying on other grains have been conducted. Schmidt and Jebe (1959) analyzed the results of some drying tests on rice. They listed the factors affecting the germination of artificially dried rice as follows: a) saturation deficit which is the difference between the saturated aqueous vapor pressures at the dry bulb temperature and the dew point temperature of the drying air; b) initial grain moisture; c) drying air temperature; and d) air velocity. With the exception of velocity, these factors accounted for 73 percent of the variability in germination. A reduction in germination occurred with an increase of each of the four factors. An increase in the air velocity from 100 to 200 feet per minute decreased the germination by 1.5 percent.

Other investigators have also studied the effects of each of the various factors on germination. Levitt (1956) states that heat hardiness of a seed is related to the amount of bound and free water in a seed. Intermicellar bridges in the seed are weakened by free water and therefore with free water present, the thermal oscillations caused by high temperatures can break the H and S-S protein bonds more easily. This causes protein denaturization (restructuring of the protein molecule) and would seem to explain why Schmidt and Jebe found that germination decreased as the initial moisture content increased.

Robbins and Petsch (1932) found that the "injurious effects of high temperatures upon a given kind of living tissue are chiefly conditioned by the degree and time of application of the heat, the water content of the tissue and the presence of liquifying or coagulating agents". In drying grain, the degree and time of heat application are related, so that changing the one usually means the other is changed also. Usually, time has little effect on seed death until a critical temperature is reached. Once this is reached, a short exposure time (compared with the time seeds are exposed to a given temperature during drying) above the critical temperature results in death. The effect of moisture content on seed viability is critical in the range of moisture contents and temperatures encountered in drying situations.

OBJECTIVES OF STUDY

The overall objective of this study was to determine the effect of drying on soybean quality and germination. Since very little was known about the effect of drying on soybean quality, preliminary tests were conducted in the fall of 1969 to determine which parameters affected soybean quality. Based largely on the results of these preliminary tests, the specific objective was to determine the effect of temperature and relative humidity of the drying air and the initial moisture content of the soybeans on germination and cracking.

EXPERIMENTAL INVESTIGATION

The experimental phase of this study involved a series of thin layer drying tests on two varieties of soybeans. The relative humidity and temperature of the drying air varied for each test.

Soybean Varieties and Harvesting Procedure

Two varieties, Harosoy 63 and Chippewa 64, were used in this study. Both of these are popular in Ohio. Harosoy 63 is an average maturing variety (121 days) and Chippewa 64 an early maturing variety (113 days). The average oil and protein content of the Harosoy 63 variety was 21.7 percent and 39.6 percent respectively. For the Chippewa 64 variety, the average oil and protein content was 21.4 percent and 40.7 percent respectively. Chippewa 64 has a yellow seed coat with a black hilum while Harosoy 63 has a yellow seed coat with a yellow hilum.

The beans were stripped from their stalks by hand on September 27 and 28, 1971, at a moisture content of about 23 percent. Both varieties were obtained from fields on The Ohio State University farm at Columbus. The beans were hand shelled and stored in a refrigerator at about 40°F. One half of each lot of shelled beans was dried to a nominal moisture content of 22 percent and the other half to 16 percent. They were dried at room temperature (72°F) without forced air movement. The beans were again placed in refrigerated storage until twenty hours before the drying tests began when they were removed to allow them to warm to room temperature.

A sample was taken from each lot before drying for a check germination test and dried to 14 percent at about 72°F without forced air movement. It was stored with the other test samples and germinated as described later.

Drying Equipment and Procedure

The dryer used by Whitaker (1967) and Baughman (1967) was modified for better humidity control. The modification included installing air preheaters ahead of the humidifying chamber and dividing the sprayers in the chamber into three manually controlled sections so that the amount of moisture added to the air could be controlled. In addition, heaters ware installed in the water reservoir to regulate the spray water temperature. With these modifications, and a warmup period of about one hour, the relative humidity and dry bulb temperature of the drying air could be controlled to within $\pm$ 5 percent and $\pm$ 3°F, respectively.

The trays (Fig. 1) for drying the beans were constructed of two 19-inch by 19-inch styrofoam boards with 15-inch diameter openings. A fine screen was glued between the boards to hold the beans. The size of the opening was reduced to 10 inches in diameter by covering the outer 2.5 inches of the screen with paper and fastening a 10-inch diameter wire ring to the screen to confine the beans to the central area. For each test, approximately 1,200 beans were dried in a tray to a nominal moisture content of 14 percent.

Four soybean samples were dried during each run. These consisted of two varieties each at two different initial moisture contents. The beans were removed from the dryer as soon as they reached a nominal moisture content of 14 percent. The beans were then weighed and a sample

Figure 1. Drying Tray

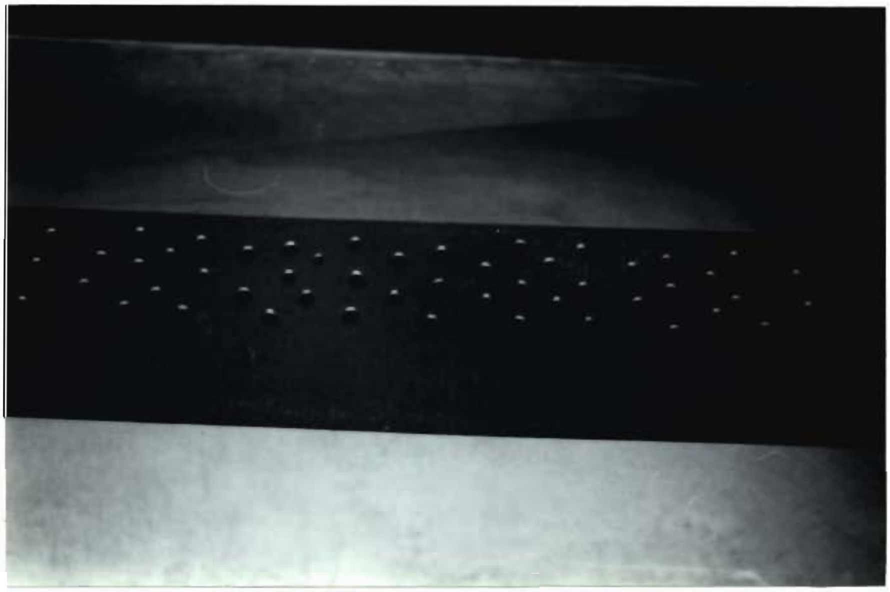

Figure 2. Soybean Arrangement on Germination Paper

taken for the oven drying test to determine accurately the final moisture content. A sample of 200 beans was also taken to determine the number of cracks which had developed during drying. All cracked beans were removed before the drying test began. The initial moisture content was determined by weighing the initial sample and calculating the initial moisture content from that determined by the oven method.

The temperature of the drying air was recorded (every 5 minutes) on a 20 point Leeds and Northrup Speedomax G. The temperature recorded was the average of five copper constantan thermocouples connected in parallel and mounted under the screen holding the beans. The relative humidity of the drying air was also taken at the same location using wet and dry bulb thermometers. All tests were conducted at a constant airflow of 100 cfm per square foot or 55 cfm per tray. It was determined by measuring the pressure drop across a perforated steel sheet similar to the one used by Shedd (1954). The airflow was regulated by controlling the total amount of air entering the dryer. This was accomplished by allowing air to escape from the transition duct before it entered the dryer.

Nine tests, each with a different combination of dry bulb temperature and relative humidity, were conducted on each of the two varieties. A summary of the initial moisture contents, drying air temperatures and relative humidities used in the tests is given in Table 1. Relative humidities of 60 percent at 130°F and 40 and 60 percent at 150°F could not be obtained with the drying system available for these tests. In actual drying sutuations, these conditions would not likely occur and thus not much would have been gained by running tests at these conditions.

Soybean Germination

After drying, germination tests of 200 beans from each test were conducted at the Ohio Seed Improvement facilities using their standard testing procedure for soybean germination tests. A test consisted of placing 50 beans on four sheets of heavy duty germinating paper, covering the beans with paper towel paper (Fig. 2), and then rolling the paper and beans into a two to three inch diameter roll. (See Fig. 3.) Four rolls were grouped together (Fig. 4) and placed in a germination chamber kept at 70°F for one week (Fig. 5). During this time the rolls were kept damp by periodic sprinkling. At the end of one week (Fig. 6), the rolls were removed from the chamber and the beans checked for germination (Fig. 7). A bean was counted as germinating if the roots, stems and leaves showed no damaged parts. A plant with any of these parts damaged would probably not survive under field conditions and thus was not counted as having germinated.

Analysis of Data

The data were analyzed by the method of least square analysis of data with unequal subclasses Harvey (1960). The mathematical model which underlies the analysis is based on the following equations:

$$x_{ijklm} = a_x + v_i + t_j + (vt)_{ij} + b_1H_{ijklm} + c_1G_{ijklm} + d_1M_{ijklm} + e_{ijklm}$$

$$y_{ijklm} = a_y + v_i + t_j + (vt)_{ij} + b_2H_{ijklm} + c_2G_{ijklm} + d_2M_{ijklm} + e_{ijklm}$$

Figure 3. Soybeans Rolled in Germination Paper

Figure 4. Rolls Ready for Germination Chamber

Figure 5. Germination Chamber

Figure 6. Soybeans at the End of One Week

Figure 7. Germinated Soybeans

$$z_{ijklm} = a_z + v_i + t_j + (vt)_{ij} + b_3 H_{ijklm} + c_3 G_{ijklm}$$

$$+ d_3 M_{ijklm} + e_{ijklm}$$

$i = 1, 2$

$j = 1, 2, 3, 4$

$k = 1, 2, 3$

$l = 1, 2, 3, \ldots, 10$

$m = 1, 2, 3, \ldots, 10$

where,

x_{ijklm}, y_{ijklm}, z_{ijklm} = the average percent germination, percent change in germination and percent cracks, respectively, for the m moisture content class in the l check germination class in the k relative humidity class in the j temperature class in the i variety class,

a_x, a_y, a_z = the theoretical population mean with equal subclass frequencies when relative humidity, check germination and initial moisture content are equal to zero,

v_i = effect of the i variety,

t_j = effect of the j temperature,

$(vt)_{ij}$ = interaction effects for variety and temperature,

b_1, b_2, b_3 = partial regression of relative humidity on germination, percent change in germination and percent cracks respectively,

c_1, c_2, c_3 = partial regression of check germination on germination, percent change in germination and percent cracks respectively,

d_1, d_2, d_3 = partial regression of initial moisture content on germination, percent change in germination and percent cracks respectively,

H_{ijklm} = relative humidity of the drying air for a given test run,

G_{ijklm} = check germination for a given test run,

M_{ijklm} = initial moisture content for a given test run,

e_{ijklm} = random errors.

A limitation of this analysis is that the results are based on only one season. Thus, the generality of these results may be limited because of the effect of preharvest factors. Although no statistical analysis was performed on the data collected in 1969, the cracks did occur at the same temperature and relative humidity levels as reported later.

Results

A summary of the results of the drying and germination tests are given in Table 1. The least squares means are given in Table 2 and the temperature-variety subclass means are plotted in Figs. 8 and 9. The results of the analysis of variance are given in Table 3 with the average percent of seed coat cracks plotted in Fig. 10.

The cracks referred to in the following discussion are cracks in the seed coat (Figs. 11 and 12). These cracks are described in more detail in the section on discussion of results.

Variety Effect

The variety effects on germination were not significant. Both varieties were affected similarly by the temperature of the drying air. Both maintained a germination percentage above 80 percent until the drying air temperature reached 150°F, and then the germination of both dropped sharply. The Harosoy 63 variety germination was reduced to about 25 percent

TABLE 1. Results of Drying Tests

Variety	Temperature °F	Relative Humidity	Initial M. C.	Germination Check	Germination Test	Germination Differ.	Cracks
				Pct.	Pct.	Pct.	Pct.
Chippewa 64	90	25	20.4	59.5	69.5	+10.0	4.5
			17.9	71.5	65.0	- 6.5	1.5
		40	20.3	58.5	70.0	+11.5	0.0
			15.2	86.0	91.5	+ 5.5	0.0
			21.2	58.5	71.0	+12.5	0.0
			15.3	86.0	91.5	+ 5.5	0.0
		60	20.6	58.5	76.5	+18.0	0.0
			15.5	86.0	90.5	+ 4.5	0.0
			20.1	58.5	74.0	+15.5	0.0
			15.3	86.0	88.5	+ 2.5	0.0
	110	20	19.8	58.5	63.0	+ 4.5	15.5
			15.4	86.0	81.0	- 5.0	2.0
		40	20.8	59.5	83.5	+24.0	0.0
			15.6	86.0	94.5	+ 8.5	0.0
			20.6	64.5	79.5	+15.0	0.0
			16.1	71.5	69.0	- 2.5	0.0
		50	20.8	59.5	85.5	+26.0	0.0
			15.5	86.0	9.15	+ 5.5	0.0
	130	20	21.3	59.5	86.0	+26.5	10.5
			15.4	86.0	82.5	- 3.5	5.0
		40	20.8	64.5	82.0	+17.5	0.5
			16.4	71.5	75.0	+ 4.0	0.0
			20.8	64.5	96.0	+31.5	0.0
			16.6	71.5	71.0	- 5.0	0.0
	150	20	19.9	59.5	0.0	-59.5	13.0
			16.3	71.5	79.5	+ 8.0	9.0

TABLE 1. (Continued)

Variety	Temperature °F	Relative Humidity	Initial M. C.	Germination Check	Germination Test	Germination Differ.	Cracks
				Pct.	Pct.	Pct.	Pct.
Harosoy 63	90	25	20.5	83.5	89.5	+ 6.0	13.5
			16.2	89.0	87.0	- 2.0	1.5
		40	20.0	81.5	95.5	+14.0	0.0
			16.9	86.5	91.0	+ 4.5	0.0
			21.1	81.5	89.0	+ 7.5	0.0
			16.6	86.5	83.0	- 3.5	0.0
		60	20.9	81.5	90.5	+ 9.0	0.0
			16.6	86.5	90.5	+ 4.0	0.0
			21.2	81.5	78.5	- 3.0	0.0
			16.0	86.5	91.5	+ 5.0	0.0
	110	20	21.4	81.5	93.5	+12.0	47.0
			17.4	86.5	96.0	+ 9.5	38.5
		40	20.1	81.5	98.5	+17.0	0.0
			16.9	89.0	96.0	+ 7.0	0.0
			20.3	83.5	85.5	+ 2.0	0.0
			15.9	89.5	82.5	- 7.0	1.0
		50	21.1	81.5	95.0	+13.5	0.0
			16.2	89.0	94.5	+ 5.5	0.0
	130	20	20.6	83.5	95.0	+11.5	49.5
			17.4	89.0	92.5	+ 3.5	51.0
		40	20.8	83.5	81.0	- 2.5	2.0
			16.4	89.5	84.0	- 5.5	0.5
			20.7	83.5	82.5	- 1.0	0.0
			16.3	89.5	88.5	- 1.0	0.0
	150	20	20.4	83.5	0.0	-83.5	58.0
			16.6	89.0	60.0	-29.0	71.5

TABLE 2. Least Squares Means

Class	Right Hand Member		
	Germination		
	Test Pct.	Difference	Cracks Pct.
Mean	73.2	- 4.7	11.5
Harosoy 63	69.2	- 8.8	20.7
Chippewa 64	77.2	- 0.7	2.3
90°F	83.1	5.4	5.3
110°F	86.6	8.7	6.2
130°F	84.9	6.7	7.1
150°F	38.2	-39.7	27.6
Harosoy 63 x 90°F	82.9	5.0	5.4
Harosoy 63 x 110°F	87.1	9.2	9.9
Harosoy 63 x 130°F	81.2	3.2	13.8
Harosoy 63 x 150°F	25.6	-52.5	53.8
Chippewa 64 x 90°F	83.4	5.7	5.1
Chippewa 64 x 110°F	85.9	8.2	2.4
Chippewa 64 x 130°F	88.6	10.2	0.3
Chippewa 64 x 150°F	50.8	-26.8	1.5

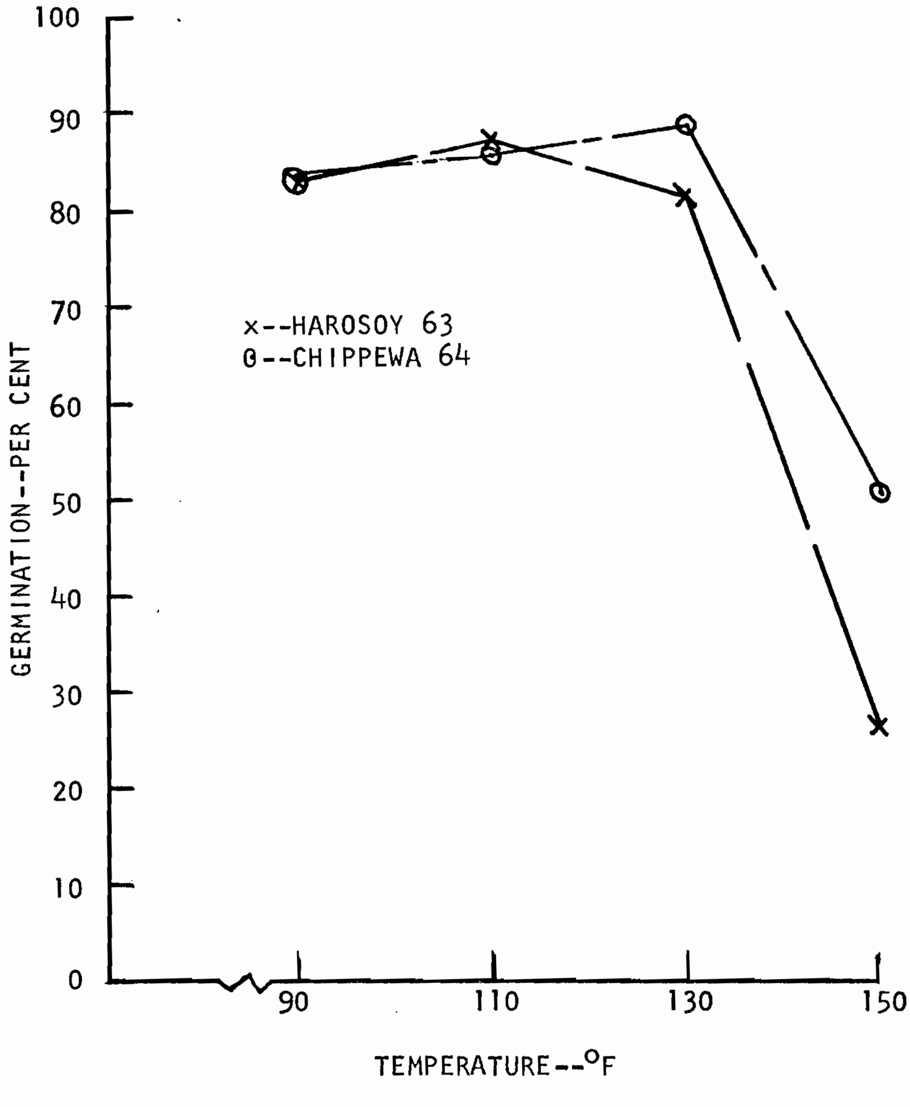

Figure 8. Effect of Drying Air Temperature on Germination

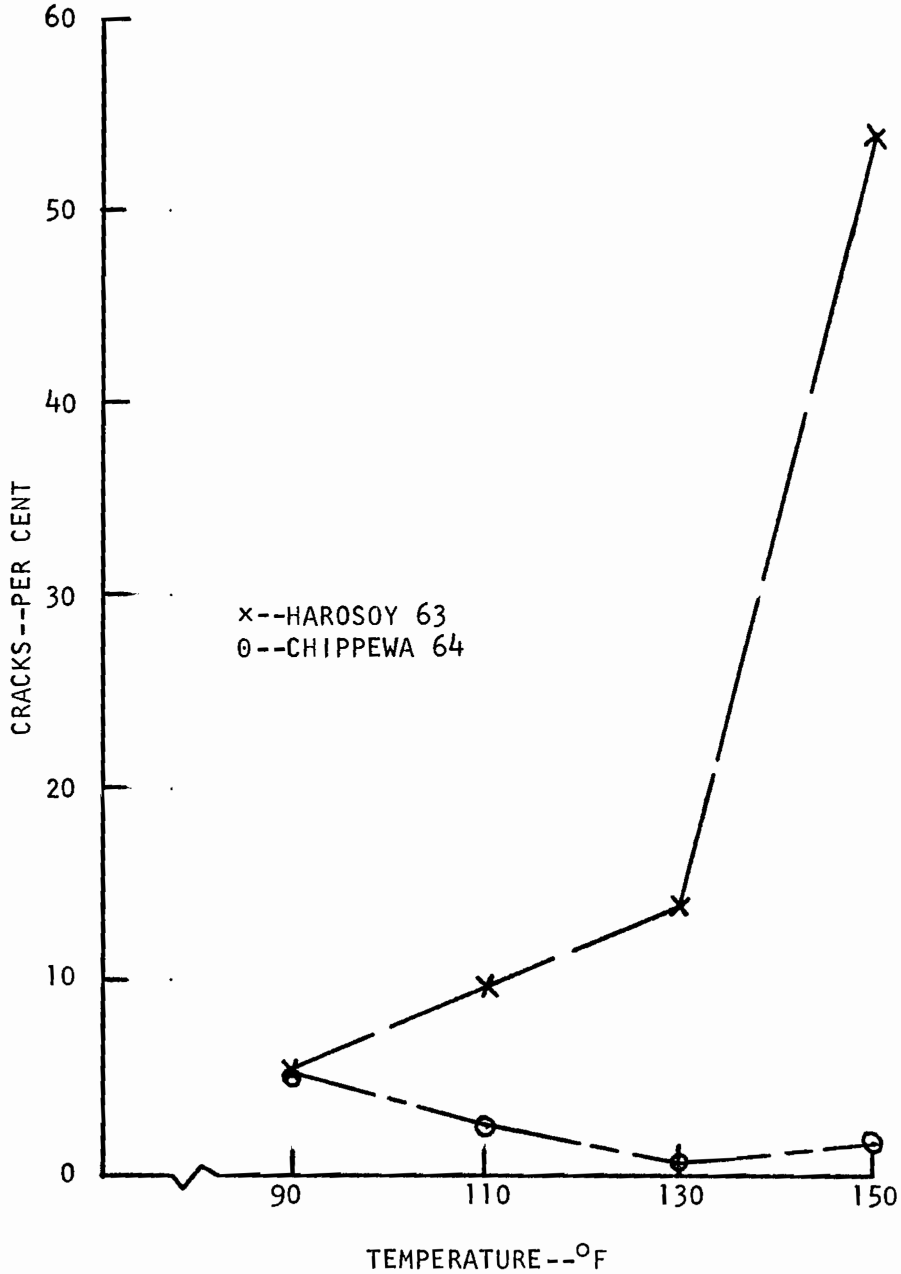

Figure 9. Effect of Drying Air Temperature on Seedcoat Cracks

TABLE 3. Analyses of Variance of Percent Germination, Percent Germination Loss and Percent Cracks for Two Varieties of Soybeans Dried During the Fall of 1971

Source of Variation	Degrees of Freedom	Mean Squares		
		Germination Test	Germination Difference	Cracks
Mean	1	174921.2***	729.1*	4338.7***
Variety	1	151.6	157.1	808.9**
Temperature	3	2274.5***	2260.4***	462.8**
Variety x Temperature	3	209.0	205.6	742.1***
Initial Moisture Content	1	29.9	38.8	27.9
Check Germination	1	537.1	60.4	3.0
Relative Humidity	1	65.5	60.2	2182.2***
Remainder	41	155.7	158.8	106.4
TOTAL	52			

* Significant at 5 percent level
** Significant at 1 percent level
*** Significant at 0.1 percent level

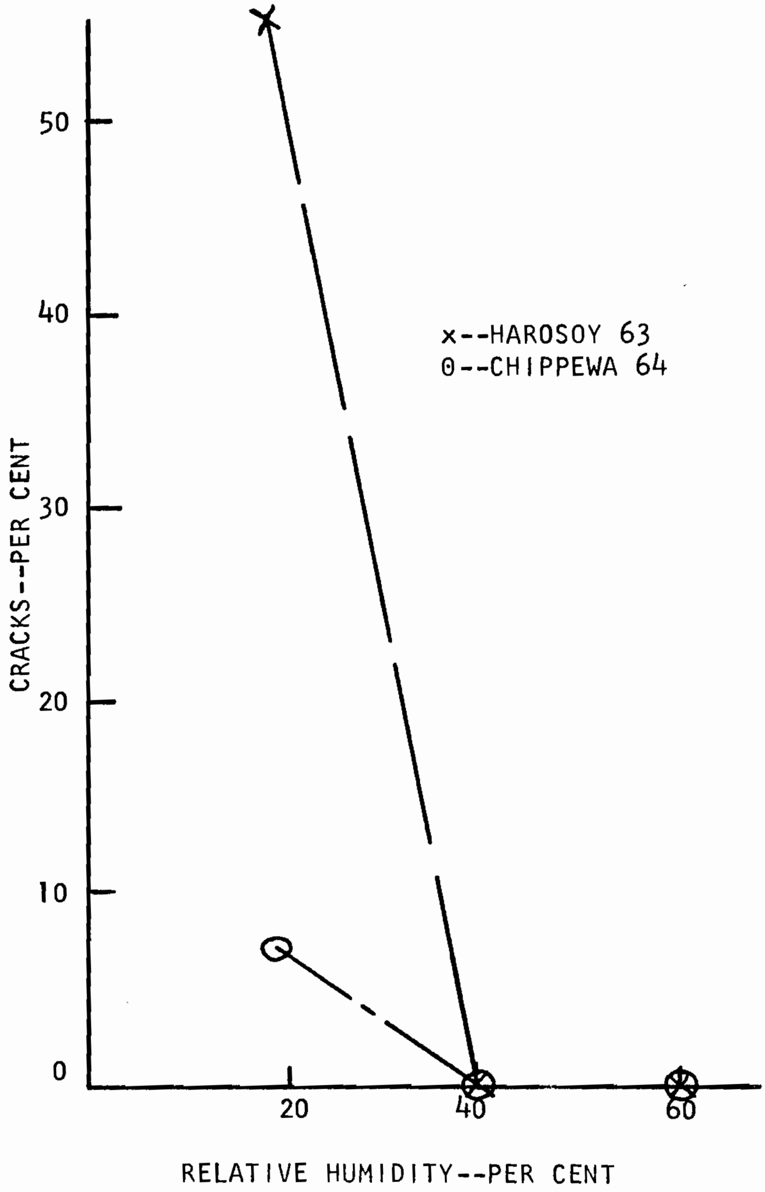

Figure 10. Effect of Relative Humidity on Seedcoat Cracks

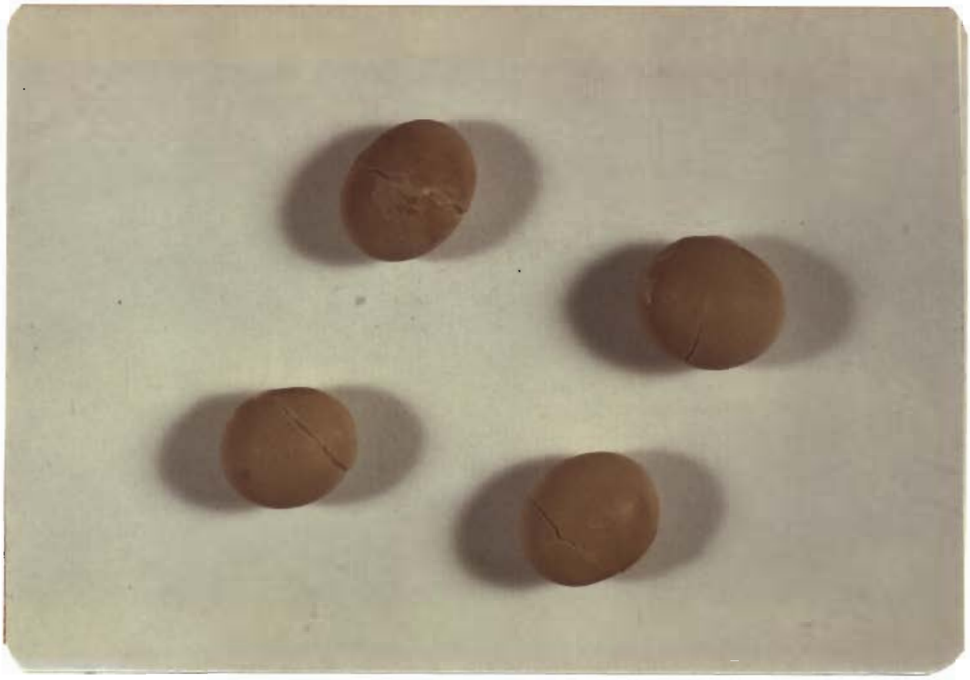

Figure 11. Seed Coat Cracks in Harosoy 63 Variety

Figure 12. Seed Coat Cracks in Chippewa 64 Variety

and the Chippewa 64 variety to about 50 percent (Fig. 8).

The variety effect on soybean seed coat cracks was significant at the 1 percent level and is clearly shown in Figs. 9 and 10. The Chippewa 64 variety cracked less than the Harosoy 63 variety, especially at temperatures of 130°F and above. The Chippewa 64 cracks at 130°F were 0.5 percent versus 14 percent for the Harosoy 63 variety. At 150°F, the difference was greater, being 1.5 percent for the Chippewa 64 variety versus 54 percent for the Harosoy 63 variety.

Temperature Effect

The temperature of the drying air affected both the germination and the seed coat cracks of the beans. As shown in Fig. 8, there was very little reduction in the germination of either variety until the temperature of the drying air was increased above 130°F. When the temperature of the drying air was raised from 130°F to 150°F, the germination of the Chippewa 64 variety dropped from 88 to 50 percent and that of the Harosoy 63 variety from 81 to 25 percent.

The temperature effect on cracks was significant at the 1 percent level. As was pointed out earlier when discussing the variety effect, the cracks in the Harosoy 63 variety were much greater, especially at temperatures of 130°F and above. At 130°F, the difference in percent cracks was 14 percent and at 150°F, 54 percent, with the Harosoy 63 variety having the larger number of cracks in both cases. At a temperature of 110°F or below, the cracks of both varieties were 10 percent or less (see Fig. 9).

Variety-Temperature Interaction

The variety-temperature interaction was not significant on germination. But this interaction was significant on seed coat cracks. As can be seen in Fig. 9, the cracks in the Harosoy 63 variety increased as the temperature increased, but the cracks in the Chippewa 64 variety decreased as the temperature increased. The cracks in the Chippewa 64 variety were about 5 percent at 90°F and decreased to about 1 percent at 150°F while the Harosoy 63 variety also had 5 percent cracks at 90°F but at 150°F, the cracks had increased to 54 percent.

Initial Moisture Content

The initial moisture content of the soybeans did not affect either the germination or the percent cracks of either variety at the levels tested (see Table 3).

Check Germination

The check germination effect was not significant (see Table 3).

Relative Humidity

The effect of the relative humidity of the drying air on germination was not significant on either variety. Its effect on percent cracks was significant at the 0.1 percent level. At drying air relative humidities of 40 percent and above, the cracks varied from 0 to 2 percent over all temperature ranges tested. When the drying air relative humidity dropped to 20 percent, the kernels with cracks ranged from 1.5 to 71.5 percent; those for both varieties over all temperature ranges tested at 20 percent relative humidity averaged 24.7 percent.

DISCUSSION OF RESULTS

From the above results, it can be concluded that the Harosoy 63 variety is much more susceptible to drying damage than the Chippewa 64 variety. These results concur with the experiences Ohio farmers have had in drying soybeans. Generally, the yellow hilum varieties are more susceptible to drying damage than the dark hilum varieties. No explanation can be given for the differences that occurred between these varieties.

The results of these tests indicate both varieties can be dried with air temperatures up to 130°F and still have an average germination of 80 percent or above. Before this conclusion can be drawn for deep bed drying applications, further tests need to be conducted. Protein denaturization, which probably accounts for the loss in germination at high drying air temperatures, is not only temperature but time dependent. In all tests, the soybeans were exposed only to the temperature of the drying air until they were dried to 14 percent. In deep bed drying, however, the soybeans next to the incoming air are exposed to the drying air temperature for a much longer period to permit the whole bed to dry. Thus, in deep bed drying, the germination may be reduced below the values found in these tests.

The germination percentages of all the beans in these tests were not as good as expected. For some as yet unexplained reason, even beans field dried during the fall of 1971 did not germinate well. Some plant pathologists felt that a fungus may have been responsible but all samples used in these tests were checked by the Plant Pathology Laboratory at Ohio State University. No fungus could be found.

The cracks which appeared in the seed coat developed within the first 10 minutes of drying. The cracks always developed perpendicular to the long axis of the bean but generally did not develop completely around the bean (Figs. 11 and 12). Also, the cracks were not located in any particular position on the bean. In samples taken from the trays, the cracks were not oriented predominantly either on the up or downstream side of the air flow or along the sides of the beans as they were oriented in the tray. A factor which seemed to contribute to the location of the cracks was the development of wrinkles in the seed coat. The cracks consistently developed in the areas of the seed coat that were wrinkled. According to Moore, the wrinkles in the seed coat develop in the field. They are the result of alternate shrinking and expanding of the cotyledons and the seed coat caused by alternate rainy and dry weather. The wrinkles may be caused by the differential expansion and contraction of the seed coat and the cotyledons, due to differences in their physical properties (Markley 1944). Although no testing was done to determine this, the wrinkles in the seed coat, as in other material, probably weakened the seed coat allowing the cracks to develop more easily.

Another effect of the drying on the soybeans was the separation of the seed coat from the cotyledons. This was prominent in those samples having the largest number of cracks, although some separation occurred in all samples dried. The cracks always occurred in an area where the seed coat was separated from the cotyledons. If the cracks were developed completely around the bean by mechanical handling, the seed coat could easily drop off the cotyledons, allowing them to separate. This probably accounts for the large number of splits in dried soybeans.

The exact cause of the seed coat separation is not known. Since it occurs within the first 10 minutes of drying, an increase in pressure under the seed coat could develop due to the vaporization of the moisture, separating it from the cotyledons. This would be especially true if the seed coat were relatively impervious to moisture movement. Further studies need to be conducted on the cause of this separation.

TABLE 4. Composition of Soybean Used

	Fraction of Seed Pct.	Moisture Pct.	Protein Pct.	Carbohydrates Pct.	Fat Pct.	Ash Pct.
Cotyledons	90	10.6	41.0	14.6	20.8	4.4
Germ	2	12.0	37.0	17.3	10.5	4.1
Seed Coat	8	12.5	7.0	21.0	0.6	3.8

The relative humidity of the drying air was the major factor determining whether seed coat cracks occurred. Cracking occurred at relative humidities of 20 percent but none occurred at relative humidities higher than 40 percent. Although Schmidt and Jebe (1959) used saturation deficit as one of the parameters of the drying air, it is not as good an indicator of cracking as relative humidity. For a given dry bulb temperature, the higher the saturation deficit, the more likely cracking will occur. But at other dry bulb temperatures, the relationship does not hold. For instance, at 90°F and 20 percent relative humidity, the saturation deficit is 1.13 inches of mercury, for 110°F and 40 percent relative humidity, it is 1.57 inches of mercury. Cracking occurred in the first but not the second case indicating that higher saturation deficits do not necessarily mean more cracks. No specific value of saturation deficit can be given to predict when cracking will occur. Because relative humidity is a better indicator of cracking, it was used in this analysis. The tests indicated that cracking was directly dependent on the ratio of the partial vapor pressure to that at saturation rather than on the differences of these vapor pressures.

The results of these tests, indicate that in practical drying situations, the relative humidity of the drying air should be kept at 40 percent or higher. Today's dryers are not adapted for providing air with a relative humidity of 40 percent or more. Some modifications would be needed. One would be to install humidifying equipment in the transition duct to increase the humidity of the air. Another possibility would be to mix exhaust air by means of a return duct with the supply air in such proportions that the desired relative humidity of the drying air would be obtained.

Low temperature drying units are the simplest to adapt to soybean drying. By simply installing a humidistat, the unit could be controlled to run only when the humidity was 40 percent or above. It could also be designed to provide heat to keep the relative humidity of the air at about 40 percent so drying could take place more rapidly. Another possibility is to dry only during the night when the humidity is high.

Drying air temperature as well as variety were factors which determined the amount of cracked beans. Figure 8 shows that temperature does not affect the cracking of the Chippewa 64 variety but that it does have a definite effect on the Harosoy 63 variety. No explanation can be given for these differences. Further studies need to be conducted to determine the causes of these differences. For the Chippewa 64 variety, the tests show that temperatures up to and including 150°F could be used for drying while still maintaining cracking below 10 percent. For the Harosoy 63 variety, any drying air temperature above 110°F would cause more than 10 percent cracks although raising the temperature to 130°F would only increase the number of cracked beans to 14 percent.

The initial moisture content of the beans did not significantly affect either the germination or the number of cracked beans. The reason for this is probably that an initial moisture content of 20 percent was not high enough to cause any differences. Schmidt and Jebe did not find any influence of initial moisture content on germination until the initial moisture content was above 20 percent. Twenty percent was used in these tests because from a practical harvesting standpoint, beans above 20 percent cannot be harvested satisfactorily with today's equipment. Even beans between 17 and 20 percent are not in very good condition after harvesting.

Even though the initial moisture content was not statistically significant, it did seem to affect the germination of both varieties at the 150°F temperature level. As shown in Table 1, none of the beans of either variety germinated when dried from the higher initial moisture content at 150°F, but at the 16 percent initial moisture content level and at the 150°F temperature level, the Harosoy 63 variety and the Chippewa 64 variety had a germination percentage of 60 and 79.5 percent, respectively. This difference in germination could have been due either to the temperature level or the time factor as the beans with the higher initial moisture content were on the dryer about twice as long as those with the lower initial moisture content.

CONCLUSIONS

This investigation produced basic data on the effects of drying on soybean germination and seed coat cracking. As a result of this study and analysis, the following conclusions can be made.

1. No seed coat cracks will develop in either the Harosoy 63 or Chippewa 64 variety if the relative humidity of the drying air is 40 percent or above.

2. Drying air temperatures above 130°F will cause the germination of both varieties to drop below 80 percent.

3. The Harosoy 63 variety is more susceptible to drying damage than the Chippewa 64 variety, both from the standpoint of loss in germination and the number of seed coat cracks which develop.

4. The initial moisture content of the soybeans, within the range used in this test, has no effect on germination or the number of seed coat cracks.

5. The effect of increasing the drying air temperature on the seed coat cracks is to increase the number in the Harosoy 63 variety but to decrease them on the Chippewa 64 variety.

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