DRYING OF WHITE BEANS — EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON SEED COAT DAMAGE

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Contribution no. I. 609[2], received 1 May 1984, accepted 28 September 1984.

Otten, L., R. Brown, and W. S. Reid. 1984. Drying of white beans — effect of temperature and relative humidity on seed coat damage. Can. Agric. Eng. **26**: 101–104.

Drying damage was assessed for white beans dried with commercial grain dryers and also with a laboratory-scale, thin-layer drying apparatus. At moderate drying temperatures (40–45°C) there was a significant increase in damage level in only two of eight tests with the commercial grain dryers. Consequently, the amount of damage attributable to artificial drying was minor compared to that which had occurred prior to drying. The thin-layer drying experiments demonstrated that humidity of the drying air was the key factor in controlling seed coat cracks. Seed coat damage was negligible if relative humidity of the drying air was 30% or greater. A simple and rapid chemical staining technique, the Indoxyl Acetate Test, was investigated as a tool to speed up the determination of seed coat damage in white beans. The test was found to be useful and showed a positive correlation with the visual damage results.

White beans, also known as Navy or pea beans, are traded and stored at 18% moisture content (wet basis). Usually this moisture level is attained by natural drying or by letting the beans dry in the swath before combining. Nevertheless in some years persistent wet weather conditions prevent normal field drying, and rather than risk spoilage of the crop producers harvest the beans moist. Some bean producers have on-farm grain drying facilities used primarily for other crops, that can be used to dry wet beans when necessary. The majority of wet beans, however, are dried at commercial grain elevators using dryers designed primarily for shelled corn.

The effects of artificial drying conditions on the final quality of edible beans are not well understood. A general opinion encountered throughout the industry is that in a wet harvest the usual reduction in bean quality due to splits and seedcoat damage is caused by artificial drying, even when air temperature is limited to 40°C. Few studies have been published on white bean seed coat damage and associated losses, and the majority of these are concerned only with damage caused by harvesting equipment (Narayan and Stout 1972; Pickett 1973; Singh and Linvil 1977). Results of those studies indicate that mechanical damage should decrease at higher moisture contents if the combine is properly adjusted.

In contrast, the effect of artificial drying on soybeans is well documented. Seedcoat and cotyledon cracks have been reported for soybeans dried in thin layers (Pfost 1975; White et al. 1980) and with farm dryers (Hirning 1973). Breakage caused by handling increases for beans which have seedcoat cracks (Chanchai et al. 1976). Drying damage also reduces viability of soybean seeds, and increases the rate of mold development and free fatty acid accumulation in storage (White et al. 1976). Morphological similarities between the seeds of white beans and soybeans suggest that the two crops should have similar responses to drying; however, the histological and biochemical properties are not similar and differences in quality should be expected. In fact, Hutchinson and Otten (1983) found the thin-layer drying rates to be similar but white beans appeared to be as much as eight times more susceptible to seedcoat cracks than soybeans. Consequences of drying damage in white beans can be anticipated to be proportionally more serious than in soybeans because the processing requirements for white beans are more stringent.

The study presented in this paper was undertaken to clarify the relationship between moisture content at harvest and physical damage in white beans after drying. Thus, the effect of air temperature and relative humidity on seedcoat cracks and splits was investigated for white beans dried with full-scale, continuous-flow grain dryers at two commercial elevators and also for beans dried in thin layers with a laboratory-scale dryer.

FIELD STUDIES

The most common dryer design at commercial elevators in Ontario is the crossflow column type which is used to dry beans as well as shelled corn. The Ace model T1875D (Dorssers Welding Co. Ltd., Blenheim, Ont.) dryer located at Hensall Co-operative (Hensall, Ontario) is typical of this design. This four-column dryer has a rated capacity of 40 tonnes/h for corn dried from 25 to 15% moisture (Otten et al. 1980) using air at 70–80°C. In this dryer the direction of the cooling air flow is opposite to that of the drying air and the cooling air is recycled.

A Belt-O-Matic model 540 RVA (Waldor Industries, New Hamburg, Ont.) was the other commercial dryer studied (Otten and Brown 1980). This crossflow, moving-belt design is being promoted for drying edible bean crops and is located at the Waters Elevator (Parkhill, Ontario). Because of the lower drying temperatures used (40°C) no cooling section is provided in the dryer. Grain bed depth as well as drying temperature and grain flow rate can be varied with this design.

Drying air temperature was regulated to 40–47°C for both dryers in accordance with the experience of the elevator operators. The tests were conducted during October 1982 whenever there were enough wet beans available for 6 h of continuous drying. Samples of about 250 g were taken every 15 min from the beans entering and leaving the dryer once steady-state operating conditions were achieved. The samples, which were essentially at ambient temperature, were immediately tested for moisture content using a Motomco Model 919 moisture tester (Nuclear Enterprises Ltd., Winnipeg, Man.), and then sealed in plastic bags for quality analysis in the laboratory.

LABORATORY DRYING

Wet white beans of the variety Seafarer were dried in a thin layer using the laboratory drying equipment described in detail by Hutchinson and Otten (1983). With the drying apparatus temperature, humidity and flow-rate of the drying air can be precisely controlled. In this study the range of values of temperature and humidity was selected to cover those experienced under actual commercial drying conditions. Three values of temperature (40, 50, 60°C) and humidity (10, 20, 30% RH) were used. One airflow rate of 610 L/(sec·m²), typical of commercial dryers, was used. Tests were conducted twice for each combination of temperature and humidity, for a total of 18 trials.

A supply of wet beans at 24.6% moisture was stored in a freezer. For a typical experiment about 250 g of wet beans were removed from storage and allowed to warm overnight to room temperature in a sealed plastic bag. All seeds with visible cracks, splits, or discoloration were removed in preparing a 150-g sample for each test. Once the drying apparatus was adjusted and steady-state operating conditions were obtained, the bean sample was carefully arranged in a single layer on the sample tray. The beans were dried for 5 h since the drying rate was also being determined for each test. As a result, beans dried in the laboratory were much drier than those of the commercial dryer tests.

VISUAL ASSESSMENT OF DAMAGE

The 100-g subsamples of the beans taken from each elevator lot were assessed for physical damage by visual examination and sorting into five categories:

(1) *Splits or foreign matter* — any bean split in half or any material other than beans or any other bean variety in the sample.

(2) *Cotyledon cracks* — all beans with the seed coat split along the plane separating the two seed cotyledons, and with the two halves held together except where:

(a) the bean was split due to obvious mechanical damage such as a dent in the seed, or

(b) the bean was split due to spoilage and decomposition of the seed coat.

(3) *Mechanical cracks* — dented or punctured seed coats, or seed coat cracks other than between the cotyledon halves, or crushed beans. This category reflects damage by harvesting or handling equipment and possible insect damage, and is characterized by damage consistent with abrasion or mechanical impact.

(4) *Spoiled or sprouted* — any beans rotted or severely discolored over more than 25% of their surface due to mold growth or any beans sprouted with consequent seed coat rupture.

(5) *Intact beans* — no visible damage or deterioration.

The magnitude of each category was reported as a percentage by weight of the original subsamples.

The entire sample of beans used in each laboratory test was examined.

INDOXYL ACETATE TEST OF DAMAGE

An alternative procedure, called the "Indoxyl Acetate Test" (French et al. 1962; Paulsen and Nave 1979) was evaluated as a tool for rapid detection of seed damage. This test was developed to detect barely visible seedcoat cracks in soybeans and other light colored legume seeds.

Indoxyl acetate is used as an indicator of esterase activity in plant and animal cells. In the presence of esterase enzymes, indoxyl acetate is hydrolyzed to indoxyl and acetic acid. Two indoxyl molecules unite in an alkaline solution to form indigo, a blue dye. Since esterase enzymes are abundant in parenchyma cell layers below the seed coat (testa) of beans, any tear or split in the seedcoat allows the indoxyl acetate to penetrate the cell layer with the resultant formation of a blue stained area. Thus even minute cracks in the seedcoats become highly visible following treatment with indoxyl acetate.

A 0.1% indoxyl acetate-ethanol solution was prepared by dissolving 100 mg of indoxyl acetate in 25 mL of 95% ethanol and adding 75 mL of distilled water. A sample of 100 dried beans was immersed in the solution for 15 sec, then removed and blotted dry with a paper towel. A 20% solution of ammonia was then sprayed on the seeds for 10 sec from a household cleaner atomizer bottle. The beans were dried with unheated air from a small blower.

Any damage to the bean seedcoats became immediately obvious as a blue-stained area. Stained beans could be rapidly segregated and counted to yield an objective level of seedcoat damage in about five minutes per sample.

RESULTS AND DISCUSSION

Commercial Drying

Mean damage results for commercially dried beans are presented in Table I. The first five lots were dried with the Belt-O-Matic dryer, and the remainder with the Ace dryer. The increase in total damage was much less than anticipated and was only statistically significant in one case for each dryer. As expected, there was no significant difference between dried and wet beans for splits and foreign material or for the spoiled and sprouted category. This type of damage is related to field and equipment conditions at harvest rather than the drying operation. The second and third tests were conducted on very poor quality beans with more than 30% moldy seeds; however, this had no discernible effect on quality change after drying.

Cotyledon cracks increased in half of the tests, including all of the tests conducted with the Ace dryer. Seed coat cracks increased in only one instance, and

TABLE I. MEAN DAMAGE IN WHITE BEANS BEFORE AND AFTER DRYING WITH COMMERCIAL GRAIN DRYERS (n = 16)

Drying air conditions		Grain moisture content (% WB)		Splits and F.M. (%)		Spoiled and sprouted (%)		Cotyledon cracks (%)		Seed coat cracks (%)		Total damage (%)	
Temperature (°C)	Humidity (% RH)	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Belt-o-matic													
42	22	20.1	17.9	2.1	3.3	5.6	5.6	2.3	3.4	7.1	6.8	17.1	19.1
38	20	20.5	18.3	1.6	1.4	30.3	33.6	1.9	2.9	4.4	3.7	38.2	41.6
43	23	21.9	18.6	2.8	3.6	34.5	33.4	2.1	3.3	1.4	1.7	40.8	42.0
41	38	20.7	18.2	0.7	1.1	3.4	2.5	0.5	0.9	1.2	1.4	5.8	5.9
34	20	19.6	17.8	0.1	0.2	4.6	5.8	0.3	1.5†	4.1	5.4	9.1	12.9†
Ace													
47	10	22.2	18.2	1.5	1.3	10.4	8.8	1.4	5.4†	3.3	8.8†	16.6	24.3†
42	25	21.2	18.0	1.8	1.7	7.7	8.7	1.5	3.1†	6.9	6.7	17.9	20.2
43	22	21.4	18.3	3.0	1.8	7.6	8.5	1.3	1.9†	5.5	6.6	17.4	18.8

†Indicates that the difference between mean values for wet and dry beans is significant according to the T-test at the 0.01 probability level.

in that test the dryer had been operated at a higher temperature (47°C) than usual.

In all cases, the amount of damage attributable to artificial drying was minor compared to that which had occurred prior to drying. The amount of moisture removal varied from 1.8 to 4 percentage points, a range which the elevator operators considered to be typical for drying beans in most years. Final moisture content of the dried beans was generally 18 ± 0.5% on a wet basis.

Thin-layer Drying

The thin-layer drying damage results are presented in Table II. Since only undamaged beans were used in each experiment, the results represent damage caused by drying only. Analysis of variance conducted on the results revealed that relative humidity of the drying air had a significant effect ($P = 0.01$) on the formation of seedcoat cracks for a given air temperature; that is, a reduction in humidity caused an increase in seedcoat cracks. With humidity held constant, however, increased drying temperature had no significant effect upon seedcoat damage. These results indicate that damage caused by heated air drying of white beans is due to the reduced humidity of the drying air rather than the increased temperature, apart from the obvious dependence of relative humidity on air temperature.

TABLE II. MEAN PERCENTAGE OF WHITE BEANS WITH VISIBLE SEEDCOAT CRACKS AFTER DRYING AT VARIOUS AIR TEMPERATURES AND HUMIDITIES IN A LABORATORY THIN-LAYER DRYER

Relative humidity of drying air (%)	Drying air temperature (°C)		
	40	50	60
10	17.2	19.3	14.2
20	8.4	9.5	7.0
30	3.6	3.8	3.6

At 30% relative humidity the damage level was below 4% over the entire temperature range. Since this damage level was for fully-exposed thin-layer drying, the equivalent level for a bed of beans made up of many individual layers would be somewhat lower, due to simultaneous cooling and humidification of the airstream as it passes through adjacent seed layers. Also, the final moisture content of the beans dried in a thin layer was up to 7 percentage points lower than typical for commercial drying.

Thus, a grain dryer operated at relative humidities above 30% should cause negligible seedcoat cracking. Humidity may be regulated either by adjusting drying temperature or by recycling moist exhaust air through the drying fan.

Indoxyl Acetate Test Results

The relationship between the visually determined damage level and the results of the indoxyl acetate test for white bean seeds is illustrated in Fig. 1. The correlation between the two parameters was significant ($r^2 = 0.58$) and the linear regression line of best fit is shown. Although there is a positive correlation, the uncertainty due to error of estimate is too great for prediction of visible seedcoat cracks from the results of indoxyl acetate tests. It was observed that sound seeds with some surface mold stained blue even though the seedcoat was intact. Also, the area around the hilum or attachment point of the seed was occasionally stained by the indoxyl acetate.

These factors contributed to the uncertainty of the results; however, it is also likely that small cracks which are not visible to the unaided eye become apparent after staining. Generally the seedcoat damage level apparent with the indoxyl acetate test was greater than visual examination would indicate. In practice, the staining technique probably gives a more objective measure of damage because it is less dependent on the visual acuity and meticulous examination of the inspector. It also greatly reduces the time required to assess each sample.

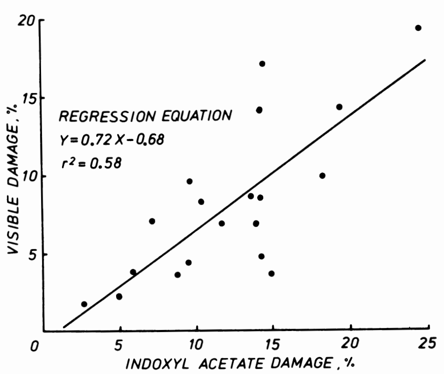

Figure 1. Comparison of the damage levels obtained by visual inspection and the indoxyl acetate tests.

CONCLUSIONS

The extent of damage done to white beans by artificial drying, as indicated by cotyledon and seedcoat cracks, was much less severe than anticipated from comments made by elevator operators. The physical damage level was significantly higher after drying in only two out of eight tests conducted with full-scale drying systems at commercial grain elevators. In all cases the drying damage was minor relative to the mechanical damage incurred prior to drying. Beans dried in thin layers in the laboratory also exhibited a low level of seedcoat cracking under moderate conditions of drying air temperature and relative humidity (40–60°C and 30% RH).

Relative humidity of the drying air is the critical factor in preventing seedcoat cracks during the drying process so that drying with air at 30% relative humidity or higher is recommended for white beans. This humidity level can be achieved by careful regulation of air temperature or by recycling moist exhaust air. Of course, the increased humidity level will result in a reduction in the driving force for the drying process and hence, a corresponding reduction in the dryer's capacity. But unlike drying of grain corn, the drying capacity is normally not a limiting factor in the bean drying process.

In a wet harvest season, when artificial drying becomes necessary, more care should be taken in adjusting and operating the harvesting equipment. Also transfer operations within the elevator should be examined since it is likely that more damage will be done in moving the beans to and from the dryer than is caused by the drying process itself.

The indoxyl acetate staining technique for evaluation of seedcoat damage in white beans indicates a higher level of damage than visual examination alone. This increase may be real, but in some instances it is the result of surface mold on the seeds. In any case the technique greatly reduces the time and tedium of sample evaluation. This or a similar technique would be useful if developed into a standard method for damage assessment.

ACKNOWLEDGMENTS

The field studies referred to in this paper were part of an edible-bean drying project funded by the Agricultural Engineering Research and Development Program of Agriculture Canada (Contract File #34SZ.01843-0-ME12). The thin-layer drying work is part of the transport properties research funded by NSERC.

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