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THE EFFECT OF DRYING TEMPERATURE ON CORN SEED QUALITY

Iowa State University PH.D. 1981

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The effect of drying temperature on corn seed quality

by

Robert Joel Navratil

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INTRODUCTION

In an effort to maintain seed quality, corn (_Zea mays_ L.) is mechanically dried to 11-12% moisture. However, this process has often been associated with significant reductions in seed quality. A more complete understanding of dryer-induced injury would therefore be desirable to maximize drying efficiency while minimizing potential damage.

As early as 1913, Dorchester and Smith (7) recognized the importance of harvest maturity and the avoidance of freezing temperatures on subsequent seed corn performance. By 1925, Duncan and Marston (8) noted that germination decreased as immaturity at harvest and drying temperature increased.

In 1929, Harrison and Wright (10) reported that corn artificially dried at temperatures of 40 to 45 C was not injured whereas corn dried at 50 C was damaged. They also found that no damage occurred when seed corn was overdried to four percent moisture at nonharmful temperatures. The work of Kiesselbach (11) generally confirmed the findings of Harrison and Wright with one exception. He recommended that temperatures be held below 40.6 C when initial seed moisture content approached 50%. At a drying temperature of 44.5 C he found no significant difference in dryer injury among 26 representative hybrids ranging in initial moisture content from 16 to 38%.

Preliminary histological observations by Washko (24) indicated a possible relationship between drying damage and plasmolysis. He also reported disintegration of the meristematic cells of the primary root and disintegration of the cells of the first internode bordering the seminal roots. However, similar injuries were not found in the plumules. He also suggested that tolerance to heat injury at later harvests was related to an increased bound water content, and that injury was related to a change in membrane integrity.

Reiss (21) found that inbred line R4 was more tolerant to high drying temperatures than inbred line WF9. He also noted that both viability and seedling vigor were significantly greater for seed dried at 37.8 C than for seed dried at 43.3 or 48.9 C. Meanwhile, Wileman and Ullstrup (25) reported that seed dried at 48.9 and 54.4 C showed no appreciable reduction in germination when initial moisture contents were 20-25% and 20% respectively. McRostie (15) showed no appreciable damage resulting from the use of drying temperatures up to 54.4 C when the initial moisture content was 30%. Dimmock (6) suggested that improved seed quality could be obtained if commercial hybrids were the progeny of inbred lines which were tolerant of high drying temperatures. He also recommended a drying temperature of 42.2 $\pm$ 0.8 C for corn containing up to 35% moisture at harvest.

Livingston (13, 14) found that the ability of the seed to produce a strong vigorous seedling under cold stress conditions was reduced by drying at 40 C. He attributed this to physiological differences between the artificially and naturally dried seed that affected their susceptibility to soil pathogens. Struve (23) suggested that vigor losses of seeds, dried in a vacuum oven in a matter of hours, were due to the prevention of certain protoplasmic adjustments. Gausman and coworkers (9) found significant differences in niacin, pantothenic acid, riboflavin, and pyridoxin when seeds were dried at 53.9 and 43.2 C. However, only pantothenic acid and riboflavin showed significant differences when the corn contained less than 40% moisture.

These combined data indicate that artificial drying may result in a variety of internal effects which could contribute to reduced germination and vigor. Differential responses to artificial drying have also been noted. The objective of this study was to test some of the most widely grown inbred parents for tolerance to dryer-induced injury, and, as part of an ongoing project, to begin to determine the physiological basis of dryer-induced injury.

MATERIALS AND METHODS

Field Plantings

Field plantings, using seed obtained from Clyde Black and Son, Inc., Ames, Iowa, were made in 1979 and 1980. Plantings were made at the Iowa State University Curtiss Farm and at the Iowa State University Bruner Farm in 1979 and 1980 respectively. The inbred parents A632, B37, B73, and Mo17 were used in 1979 and A632, A641, B73, and Mo17 were used in 1980. Inbreds were planted in four- to six-row plots approximately 150 m long. No randomization of the inbred rows was attempted. The single cross H99 x H95 was used as a common pollinator in both years. Adequate planting dates and pollinator row spacings were used to insure complete inbred pollination. Because of severe environmental stress, however, A641 was not pollinated satisfactorily and was dropped from the study. A minimum of eight pollinator rows were planted around the perimeter of each field. Inbred plants were hand detasseled and tasseling dates were recorded.

Laboratory Drying

Random ear samples from each inbred parent were collected periodically, during both harvest seasons, to obtain ears with moisture percentages ranging from approximately 45-50% to approximately 20% in five harvest dates. In 1979, however, only four harvests of A632 were made ranging from 43% to 19% moisture.

At each harvest, samples were brought into the laboratory, husked, and black layer determinations were made as described by Knittle and

Burris (12). Four subsamples of ten and six ears each in 1979 and 1980 respectively were then placed in each of four experimental dryers (18). In 1979, subsamples were placed in the dryers with respect to a randomized complete block design to attempt to minimize the effect of any temperature differences from the top to the bottom of the dryers. In 1980, due to space constraints, the placement was completely random.

Each dryer was operated at a different temperature. Mean temperatures of 35, 40, 45, and 50, all $\pm$ 0.3 C, were used to dry the subsamples to approximately 12% moisture.

Ambient air was relatively constant at 22 $\pm$ 1 C. Relative humidity was monitored with a hygro-thermograph in 1980 and was found to be 45 $\pm$ 5%. No determinations of relative humidity were made in 1979. Since the system used here approximated thin layer drying, it was assumed that drying rate was dependent on the seed and the properties of the air surrounding the seed. Different airflow rates of 1.3 and 18.4 L/sec/m^2 were therefore used in 1979 and 1980 respectively, depending on stack height, to insure that moisture leaving the seed would not greatly affect the properties of the air surrounding the seed.

A Delmhorst model G-6 moisture meter was used to determine when seed was dry. The subsamples were then hand-shelled, put in paper bags, and placed in cold storage at 10 C and approximately 50% relative humidity to equilibrate to 11% moisture. This equilibration period was used to minimize the effect of variations in final moisture content.

Laboratory Tests

Main experiment

Laboratory tests included moisture content determinations of the seed before and after drying using the oven method specified by the American Society of Agricultural Engineers (1). Seed weight at each harvest was also determined. Fifty Captan-treated seeds from each subsample were then subjected to standard tests for germination and seedling vigor which were performed as previously described (17). A standard cold-test was also conducted on 100 seeds from each subsample using method A as previously described (4).

Statistical analyses were subsequently performed on A632, B73, and Mo17 subsample means combined over years. Expected mean squares were used to select the correct denominator for tests of significance. Inbred parents (I) were tested with the year (Y) by I interactions. Drying temperatures (T) were tested with the Y by T interactions and the I by T interactions were tested with the Y by I by T interactions. When either the Y by T or Y by I by T interactions were not significant they were pooled and the appropriate test was made using the pooled error term.

Due to the unbalanced and continuous nature of the harvest moisture data, the linear component of harvest moisture (ML) was used in the analyses. Mean squares for sources of variation involving ML were calculated using type IV sums of squares. When the proper denominator was not significant, it was pooled with the error term and, once again, the appropriate test was made using the pooled error term. Components which had a $P > F$ of 0.30 or less were then used to predict mean values for each quality measurement. Data from B37 in 1979 were treated separately. The error term was used to test all sources of variation for those analyses. Significant ML, T, and ML by T components were then used to predict values for each quality measurement.

Exhaustion tests

Seed that had been dried at 35 and 50 C from the second and third harvests of A632, B73 and Mo17 in 1979 were also subjected to an extended grow out period. The procedure used was similar to that used for the standard germination and vigor tests with the following exceptions. Five preweighed seeds from each of the 12 inbred-harvest-drying temperature combinations were planted in ten rolled towels each. One towel from each combination was then placed in each of ten plastic buckets for a 16-day grow out period at 25 C in the dark. At the end of that time, the remaining dry weight in the kernels from the normal seedlings was recorded and initial dry weight was determined by adjusting for initial seed moisture. The percent dry weight remaining in the seed as well as the percent dry weight that was transferred to the shoots and roots of the normal seedlings was then calculated. Treatment means and their standard errors were then computed.

Effect of temperature without drying

In 1980, seven representative subsamples of three ears each were visually selected from each A632, B73, and Mo17 harvest. They were subsequently dipped in a solution of 100 ppm streptomycin sulfate, 300 ppm tetracycline and 100 ppm penicillin G and dusted with Captan.

One subsample was then put on wire racks in cold storage for drying to 11%. The other six subsamples were wrapped in a low barrier plastic wrap. Three of the subsamples were then placed in a 35 C oven and the remaining three were placed in a 50 C oven. At three, six, and twelve hours one subsample was removed from both of the ovens, unwrapped, and also placed in cold storage. An electric fan was used to facilitate air movement around the treated ears. When the ears were equilibrated to approximately 11%, two 50-seed replicates per treatment were subjected to the standard test for germination. Treatment means and their standard errors were again calculated.

Rate of drying

In 1980, subsamples of A632, B73, and Mo17 with beginning harvest moistures of 52, 49, and 47% respectively were removed from the dryers at 12-hour intervals until seed moisture was below 15%. The slope of the regression of seed moisture on hours in the dryer was subsequently calculated for each maternal parent at all four drying temperatures.

Effect of overdrying

Four additional four-ear subsamples of Mo17 were randomly placed in the dryers at each drying temperature at all but the first harvest in 1980. These subsamples were then overdried for a seven-day period. They were subdivided with one half sealed in plastic and the other half put in a paper bag. Both halves were then placed in cold storage where the paper bag subsamples equilibrated to 11%. The standard test for germination and seedling vigor and the standard cold-test were subsequently performed, after treating with Captan, on the overdried subsamples. Data from the overdried samples, with and without plastic, were then statistically analyzed together with the 1980 Mo17 subsamples which had been dried to 12% moisture. Tests of significance were made using the error mean square.

Field Emergence

Subsamples from all 1979 inbred, harvest, and drying temperature treatment combinations were bulked by volume and planted on 1 May and 23 May, 1980 at the Iowa State University Bruner Farm. Seed was planted at a uniform depth of 5 cm with a conventional four-row disc-opener planter. With use of a randomized complete block design, 100 seeds of each sample were planted in two adjacent 50-seed rows spaced 75 cm apart in each of four blocks at both field plantings. Rows were 6 m long with 1.5-m alleys. Final emergence counts were made when the majority of the seedlings had reached the four-leaf stage. Emergence counts from adjacent rows were added together to get percent field emergence for each experimental unit. Statistical analyses were then performed on the combined data from both field plantings. Tests of significance were made using the error mean square.

RESULTS

Climatological comparisons of the 1979 and 1980 growing seasons are given in Table 1. July and August in 1979 were cooler than in 1980. July was somewhat wetter in 1979, receiving approximately 10 cm of precipitation compared with 5 cm in 1980. August rainfall was essentially identical in both years.

The kernel maturity indices of each maternal parent, at all 1979 and 1980 harvests, are shown in Table 2. With two exceptions, black layer development was essentially complete in all maternal parents by 70 days after tasseling. In 1979, B37 and Mo17 showed complete black layer development at 63 and 67 days after tasseling respectively. Each maternal parent showed a maximum dry weight accumulation between 30 and 36% moisture, with some decline at later harvests. Moisture content decreased at nearly a linear rate throughout the sampling period in all maternal parents in both years.

Laboratory Tests

Main experiment

The effects of drying temperature and harvest maturity, as measured by seed moisture, on measurements of seed quality for each maternal parent in 1979 and 1980, are reported in Tables 3, 4, 5, and 6. Responses within seed parents were generally consistent across years.

Maternal parent A632 was relatively tolerant of high drying temperatures (Table 3). Germination was unaffected by temperatures up to 45 C regardless of maturity. At 50 C, however, as the harvest season

Table 1. Climatological comparisons of the 1979 and 1980 growing seasons; data are from the Ames, Iowa State University Station

	Temperature (C)					
	Maximum		Minimum		Precipitation (cm)	
Month	1979	1980	1979	1980	1979	1980
May	23.1	24.3	8.3	9.9	12.3	7.3
June	27.8	27.6	14.4	14.3	16.0	10.0
July	27.9	31.5	16.8	18.2	10.3	5.1
August	27.5	29.5	16.6	16.9	12.6	13.7
September	25.8	24.9	10.9	10.5	6.5	3.8

Table 2. Kernel maturity indices of four maternal parents harvested in 1979 and 1980

Year	Maternal parent	Maturity index	Date of harvest				
			1	2	3	4	5
1979	A632	Days after tasseling	—	48	59	63	74
		Black layer	—	—	3	4	5
		Dry weight[a]	—	22.6	25.9	26.0	25.5
		Moisture (%)	—	43	34	31	19
	B37	Days after tasseling	38	45	53	63	73
		Black layer	—	3	4	5	5
		Dry weight	21.2	24.9	27.4	26.0	26.6
		Moisture (%)	45	40	36	29	24
	B73	Days after tasseling	42	53	60	68	78
		Black layer	—	3	3	4	5
		Dry weight	16.6	21.1	20.8	22.9	24.4
		Moisture (%)	47	39	36	31	25
	Mo17	Days after tasseling	42	52	57	67	77
		Black layer	—	3	3	5	5
		Dry weight	21.7	26.0	25.2	28.0	26.0
		Moisture (%)	47	39	36	30	23
1980	A632	Days after tasseling	43	55	62	69	76
		Black layer	1	3	4	5	5
		Dry weight	16.5	20.9	26.1	25.2	25.8
		Moisture (%)	52	40	32	26	18

[a]Dry weight in g/100 kernels.

Table 2. (Continued)

Year	Maternal parent	Maturity index	Date of harvest 1	2	3	4	5
1980	B73	Days after tasseling	43	50	57	64	71
		Black layer	1	3	4	4	5
		Dry weight	16.8	19.6	23.5	25.6	24.3
		Moisture (%)	47	43	35	32	28
	Mo17	Days after tasseling	47	54	61	68	75
		Black layer	1	3	4	5	5
		Dry weight	20.1	25.4	27.4	27.0	25.2
		Moisture (%)	49	36	34	29	25

Table 3. Seed quality measurements of maternal parent A632 harvested at different moisture contents in 1979 and 1980 and dried at 35, 40, 45, and 50 C

		1979			
		Temperature (C)			
Quality measurement[a]	Harvest moisture (%)	50	45	40	35
Germination (%)	—	—	—	—	—
	43	99	99	100	100
	34	86	99	99	100
	31	92	100	100	99
	19	99	99	99	98
Cold-test emergence (%)	—	—	—	—	—
	43	81	87	98	97
	34	60	94	99	99
	31	62	78	99	98
	19	94	98	99	99
Seedling dry weight (mg/seedling)	—	—	—	—	—
	43	41	37	52	48
	34	42	51	47	44
	31	45	46	50	50
	19	51	52	49	49
Ratio[b]	—	—	—	—	—
	43	1.18	0.98	1.04	1.22
	34	0.91	1.12	1.05	1.20
	31	0.89	0.92	0.90	0.94
	19	1.08	0.90	0.88	0.89

[a]Values are means of four subsamples.

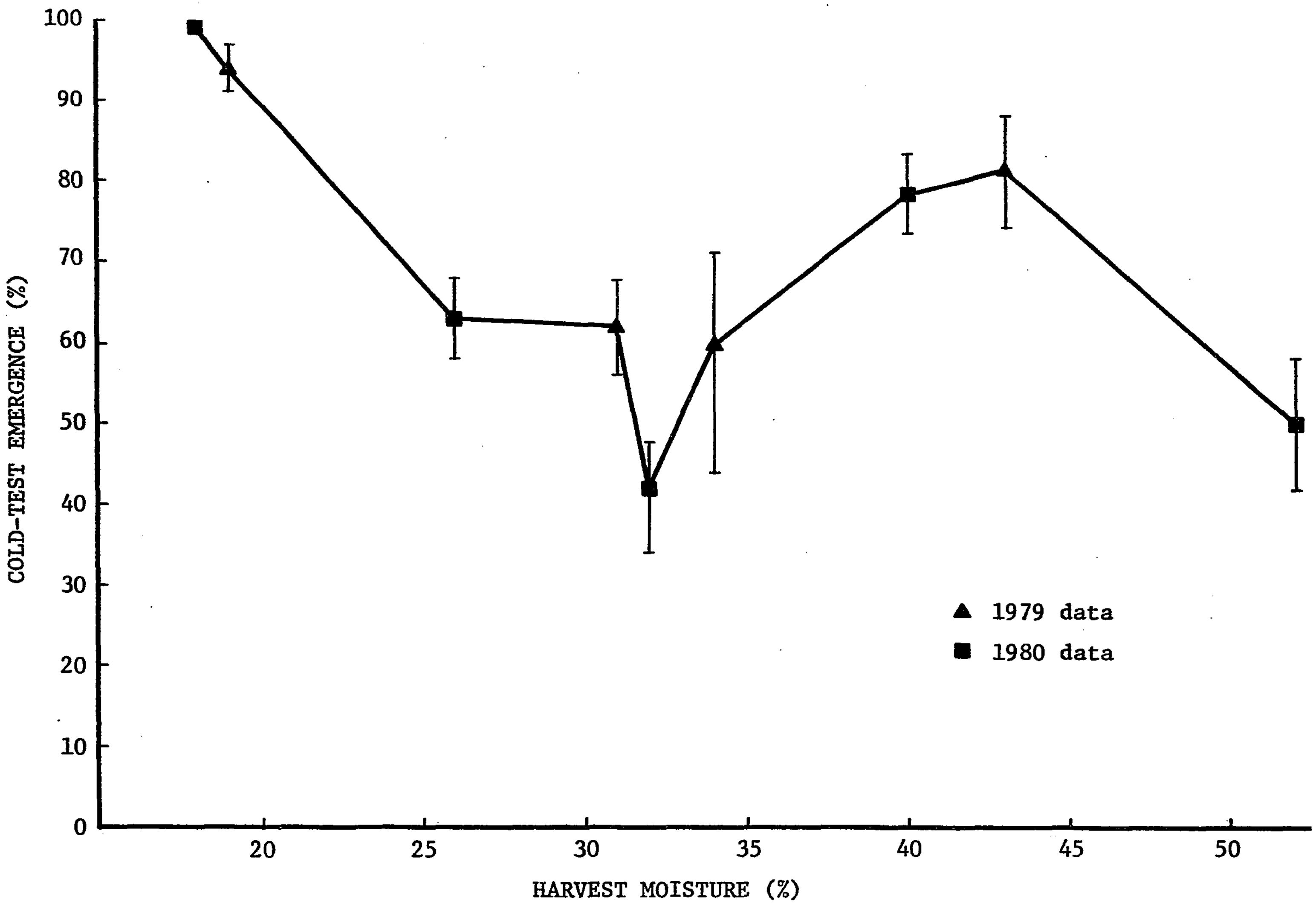
[b]Ratio of shoot to root dry weight.

1980				
	Temperature (C)			
Harvest moisture (%)	50	45	40	35
52	80	99	97	98
40	96	98	99	100
32	72	99	100	99
26	84	100	100	99
18	99	99	99	99
52	50	87	96	97
40	78	96	99	98
32	42	87	96	99
26	63	95	99	98
18	99	97	99	100
52	37	48	49	55
40	58	59	64	65
32	54	65	68	67
26	59	75	72	73
18	68	67	67	69
52	1.83	2.06	1.87	2.06
40	1.71	1.57	1.71	1.69
32	1.49	1.67	1.69	1.56
26	1.42	1.80	1.64	1.63
18	1.44	1.70	1.63	1.66

progressed, germination increased and then dropped at harvest moistures of 34 and 32% in 1979 and 1980 respectively, before increasing again in later harvests. The cold-test emergence results were similar in response to germination but were more pronounced. Except at earlier harvests, little response was noted for drying temperatures up to 45 C. At 50 C, cold-test emergence was markedly reduced until harvest moisture was less than 20%. The drop observed between 30 and 35% for germination was much more dramatic for cold-test emergence as shown in Figure 1. Seedling dry weight was lower in 1979 than it was in 1980, however, the responses to temperature and maturity were the same. At 35 C and 40 C, seedling dry weight was relatively constant, regardless of maturity, except when harvested at 52% moisture in 1980, where some decrease was noted. Seedling dry weight steadily decreased with earlier harvests when the seed was dried at 45 C. At 50 C, the effect was even more pronounced. The ratio of shoot to root dry weight was relatively constant in A632. Only at the 52% harvest in 1980 were consistently higher values noted for all drying temperatures.

Table 4 gives the seed quality measurements for inbred parent B73. Although germination was similar to A632 at drying temperatures up to 45 C, at 50 C significant reductions in germination were evident at the earliest harvest in 1979 and at all but the last harvest in 1980. Reductions in cold-test emergence were also greater than the reductions observed for A632 when dried at 50 C. Seed dried at 45 C in 1979 exhibited a cold-test emergence of less than 80% at higher harvest moistures whereas seed dried at 45 C in 1980 did not show that

Figure 1. Mean cold-test emergence for A632 harvested in 1979 and 1980 and dried at 50 C; vertical lines correspond to standard error values



COLD-TEST EMERGENCE (%)
100
90
80
70
60
50
40
30
20
10
0
20
25
30
35
40
45
50
HARVEST MOISTURE (%)
1979 data
1980 data

Table 4. Seed quality measurements of maternal parent B73 harvested at different moisture contents in 1979 and 1980 and dried at 35, 40, 45, and 50 C

		1979			
		Temperature (C)			
Quality measurement[a]	Harvest moisture (%)	50	45	40	35
Germination (%)	47	46	75	99	99
	39	85	99	99	100
	36	97	100	99	99
	31	96	99	99	99
	25	99	100	97	100
Cold-test emergence (%)	47	12	58	99	98
	39	34	61	99	99
	36	27	65	95	97
	31	44	84	98	99
	25	85	94	98	99
Seedling dry weight (mg/seedling)	47	25	25	37	42
	39	32	34	43	45
	36	38	39	46	48
	31	41	43	44	46
	25	51	50	49	54
Ratio[b]	47	2.66	2.25	1.48	1.19
	39	1.39	1.14	1.24	0.99
	36	1.27	1.30	1.00	0.96
	31	1.43	0.95	1.10	1.06
	25	1.12	1.03	1.11	1.14

[a]Values are means of four subsamples.

[b]Ratio of shoot to root dry weight.

1980				
	Temperature (C)			
Harvest moisture (%)	50	45	40	35
47	10	97	99	100
43	43	99	99	100
35	58	100	100	99
32	50	100	100	99
28	96	100	99	99
47	1	88	98	99
43	5	96	99	98
35	10	94	100	99
32	26	92	99	98
28	79	98	100	98
47	33	43	57	54
43	32	55	61	64
35	48	58	67	68
32	53	66	68	73
28	65	67	71	68
47	3.19	1.63	1.56	1.62
43	2.27	1.52	1.45	1.41
35	1.83	2.07	1.61	1.54
32	1.25	1.61	1.51	1.51
28	1.43	1.43	1.33	1.36

unacceptable level of performance at any maturity. However, some decline in cold-test emergence was noted for seed dried at 45 C at the earliest harvest. Seedling dry weight values for B73 were also lower in 1979 than they were in 1980. In both years, however, seedling dry weight generally decreased as drying temperature and/or harvest moisture increased. The response of the ratio of shoot to root dry weight to drying temperature and harvest moisture was comparable with the response noted for A632 with two exceptions. The magnitude of the response was much greater for B73, and higher values were also observed at harvest moistures of 39 and 36% in 1979 and 1980 respectively, when seed was dried at 50 C.

Seed quality measurements for maternal parent Mo17 are presented in Table 5. Like B73, Mo17 proved to be relatively intolerant of high drying temperatures. Seed dried at 50 C showed an almost linear decline in germination with earlier harvests. Although a drop at 34% moisture, similar to the one exhibited by A632, was noted for germination and cold-test emergence in 1980, no such response was apparent for Mo17 in 1979. Seed harvested at higher moisture contents and dried at 45 C also exhibited some reduction in germination percentage. Cold-test emergence was again the most responsive parameter measured. Only when initial seed moisture was below 24 and 30% were observed cold-test percentages greater than 80% for seed dried at 50 and 45 C respectively. Some decline in cold-test percentages was also noted for seed dried at 40 C at earlier harvests. The responses of seedling dry weight, and the ratio of shoot to root dry weight, to harvest moisture and drying temperature for Mo17, were similar to the responses noted for B73.

Table 5. Seed quality measurements of maternal parent Mo17 harvested at different moisture contents in 1979 and 1980 and dried at 35, 40, 45, and 50 C

		1979			
		Temperature (C)			
Quality measurement[a]	Harvest moisture (%)	50	45	40	35
Germination (%)	47	42	83	98	98
	39	44	88	98	98
	36	82	91	98	98
	30	83	93	97	94
	23	99	98	99	99
Cold-test emergence (%)	47	5	35	87	99
	39	9	44	94	97
	36	57	60	94	98
	30	51	75	84	94
	23	94	98	99	99
Seedling dry weight (mg/seedling)	47	17	31	45	53
	39	26	35	54	57
	36	41	40	49	53
	30	37	42	48	48
	23	49	49	55	51
Ratio[b]	47	1.61	1.75	1.11	1.19
	39	1.92	1.19	0.92	1.03
	36	1.11	1.12	0.92	0.82
	30	0.99	0.94	0.86	0.95
	23	0.86	0.73	0.91	0.94

[a]Values are the means of four subsamples.

[b]Ratio of shoot to root dry weight.

1980				
	Temperature (C)			
Harvest moisture (%)	50	45	40	35
49	49	95	100	99
36	51	91	95	96
34	36	91	82	90
29	92	96	92	98
25	93	100	98	95
49	7	68	82	98
36	17	61	83	89
34	17	59	75	90
29	61	84	90	95
25	71	89	98	99
49	35	49	61	66
36	39	55	58	65
34	60	52	60	59
29	58	64	59	65
25	56	64	66	64
49	2.49	2.08	1.41	1.43
36	1.63	1.44	1.34	1.34
34	1.32	1.46	1.38	1.44
29	1.33	1.47	1.40	1.16
25	1.27	1.26	1.27	1.34

Drying tolerance of inbred parent B37 seemed to be intermediate between A632 and the two intolerant parents, B73 and Mo17 (Table 6). Once again, little response in germination was apparent when seed was dried at 45 C and below, regardless of maturity. At 50 C, however, reductions in germination occurred at earlier harvests and a drop in germination and cold-test emergence, similar to the one exhibited by A632, was observed for seed harvested at 40% moisture. Similar responses in cold-test emergence were also noted for seed dried at 45 C but they were less pronounced. Seedling dry weight generally decreased as drying temperature and/or harvest moisture increased. However, seed harvested at 24% moisture, and seed dried at 35 C, did not follow that trend. The response of the ratio of shoot to root dry weight for B37 was similar to the responses noted for B73 and Mo17 but was less pronounced.

Correlation coefficients for maturity indices and germination cold-test emergence, and seedling dry weight, across years, for A632, B73, and Mo17 dried at 35 and 50 C, are reported in Table 7. At 35 C, cold-test emergence for A632 exhibited significant correlations with days after tasseling and moisture at the 0.01 and 0.05 probability levels respectively. No other significant correlations were found when seed was dried at 35 C. At 50 C, however, germination, cold-test emergence, and seedling dry weight for B73 and Mo17 were significantly correlated with days after tasseling and moisture. All three quality measurements for B73 were also significantly correlated with black layer as was cold-test emergence for Mo17. The only significant correlation involving kernel dry weight was with B73 seedling dry weight. Seed quality measurements

Table 6. Seed quality measurements of maternal parent B37 harvested at different moisture contents in 1979 and dried at 35, 40, 45, and 50 C

		1979			
		Temperature (C)			
Quality measurement[a]	Harvest moisture (%)	50	45	40	35
Germination (%)	45	82	98	98	99
	40	62	99	99	99
	36	73	99	99	99
	29	95	97	99	100
	24	99	100	100	99
Cold-test emergence (%)	45	41	89	100	99
	40	9	61	98	99
	36	27	83	98	100
	29	80	96	99	100
	24	89	98	99	99
Seedling dry weight (mg/seedling)	45	36	48	56	61
	40	38	50	58	61
	36	50	60	64	64
	29	54	62	63	59
	24	61	59	63	58
Ratio[b]	45	2.02	1.93	1.61	1.43
	40	1.86	1.65	1.52	1.33
	36	1.37	1.36	1.32	1.25
	29	1.32	1.44	1.35	1.46
	24	1.43	1.61	1.29	1.20

[a]Values are the means of four subsamples.

[b]Ratio of shoot to root dry weight.

Table 7. Correlation coefficients (r values), across 1979 and 1980, for maturity indices and germination, cold-test emergence, and seedling dry weight, for A632, B73, and Mo17 dried at 35 and 50 C

		Maternal parent		
		A632		
Drying temperature (C)	Maturity index	Germ.[a]	Cold-test emergence (%)	Seedling dry weight (mg/seedling)
35	Days after tasseling	-0.11[b]	0.87**	0.18
	Black layer	0.02	0.63	0.33
	Dry weight[c]	0.22	0.66	0.02
	Moisture (%)	0.14	-0.76*	-0.26
50	Days after tasseling	0.33	0.54	0.66
	Black layer	0.39	0.53	0.71*
	Dry weight	0.08	0.15	0.40
	Moisture (%)	-0.30	-0.52	-0.69*

[a]Germination percentage.

[b]n = 9 for A632 except for black layer where n = 8. n = 10 for B73 and Mo17 except for black layer where n = 9.

[c]Dry weight in g/100 kernels.

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Maternal parent					
B73			Mo17		
Germ.	Cold-test emergence (%)	Seedling dry weight (mg/seedling)	Germ.	Cold-test emergence (%)	Seedling dry weight (mg/seedling)
-0.30	-0.08	0.28	-0.23	0.03	-0.11
-0.38	-0.26	0.33	-0.30	0.01	-0.37
-0.37	-0.02	0.56	-0.60	-0.49	-0.32
0.34	0.04	-0.34	0.27	0.08	0.16
0.77**	0.87**	0.81**	0.81**	0.89**	0.77**
0.71*	0.78*	0.80**	0.66	0.74*	0.61
0.52	0.62	0.84**	0.28	0.36	0.55
-0.77**	-0.85**	-0.85**	-0.77**	-0.87**	-0.73*

for A632 dried at 50 C showed few significant correlations. Only seedling dry weight was significantly correlated with black layer development and moisture content.

Subsample means from A632, B73, and Mo17 were subsequently analyzed together. Results of those analyses are presented in Tables 8, 9, 10, and 11. Since the experimental design only permitted relatively weak F-tests for I, T, and the I by T interactions, the P > F values were reported. However, in spite of the weak F-tests, I, T, and the I by T interaction for cold-test emergence, and T for seedling dry weight were significant at the 0.05 level, or better, and T and the I by T interaction for the ratio variable were significant at the 0.01 level. For all dependent variables, ML was highly significant. Except for the T by ML interaction for the ratio variable and the I by T by ML interactions for cold-test emergence, which was significant at the 0.02 level, and the seedling dry weight variables, all other interactions were highly significant. Neither the quadratic or cubic components of harvest moisture were found to be significant for any of the dependent variables. Overall coefficients of determination (r^2 values), for models used to predict the values shown in Table 12, were 0.77, 0.88, 0.46, and 0.51 for germination, cold-test emergence, seedling dry weight, and the ratio of shoot to root dry weight respectively.

Subsample values from each harvest moisture and drying temperature treatment combination for B37 were analyzed separately. Results of those analyses are given in Table 13. Harvest moisture (M) for germination was significant at the 0.02 level. Except for the M by T and

Table 8. Analysis of variance for germination percentage for A632, B73, and Mo17 means

Source of variation[a]	d.f.	MS	P > F
Y	1	356.04	
I	2	794.18	0.10
Y x I	2	78.68	0.29
T	3	3854.39	0.07
I x T	6	311.48	0.30
Y x T	3	487.10	0.01
Y x I x T	6	180.53	0.01
ML	1	2019.74	(0.01)[b]
Y x ML	1	4.36	n.s.[c]
I x ML	2	485.39	(0.01)
T x ML	3	1451.12	(0.01)
Y x I x ML	2	44.91	n.s.
Y x T x ML	3	43.42	n.s.
I x T x ML	6	327.63	(0.01)
Y x I x T x ML	6	38.82	n.s.
Error	68	62.66	

[a]Y = years, I = inbred parents, T = drying temperatures and ML = the linear component of moisture.

[b]( ) tested with pooled error.

[c]Nonsignificant at the 0.50 level.

Table 9. Analysis of variance for cold-test emergence for A632, B73, and Mo17 means

Source of variation[a]	d.f.	MS	P > F
Y	1	0.04	
I	2	2683.73	0.02
Y x I	2	45.83	n.s.[b]
T	3	16236.31	0.02
I x T	6	920.23	(0.05)[c]
Y x T	3	631.10	0.01
Y x I x T	6	91.71	n.s.
ML	1	6193.14	(0.01)
Y x ML	1	125.10	0.30
I x ML	2	792.47	(0.01)
T x ML	3	2399.87	(0.01)
Y x I x ML	2	60.22	n.s.
Y x T x ML	3	190.25	0.15
I x T x ML	6	331.55	(0.02)
Y x I x T x ML	6	65.00	n.s.
Error	68	105.24	

[a]Y = years, I = inbred parents, T = drying temperatures, and ML = the linear component of moisture.

[b]Nonsignificant at the 0.50 level.

[c]( ) tested with pooled error.

Table 10. Analysis of variance for seedling dry weight for A632, B73, and Mo17 means

Source of variation[a]	d.f.	MS	P > F
Y	1	6777.47	
I	2	216.86	0.20
Y x I	2	25.97	0.19
T	3	981.88	0.02
I x T	6	50.10	0.40
Y x T	3	48.23	0.03
Y x I x T	6	39.84	0.03
ML	1	3076.31	0.01
Y x ML	1	68.34	0.04
I x ML	2	199.32	(0.01)[b]
T x ML	3	293.98	(0.01)
Y x I x ML	2	43.11	0.07
Y x T x ML	3	5.78	n.s.[c]
I x T x ML	6	31.13	(0.07)
Y x I x T x ML	6	7.83	n.s.
Error	68	15.33	

[a]Y = years, I = inbred parents, T = drying temperatures, and ML = the linear component of moisture.

[b]( ) tested with pooled error.

[c]Nonsignificant at the 0.50 level.

Table 11. Analysis of variance for the ratio of shoot to root dry weight for A632, B73, and Mo17 means

Source of variation[a]	d.f.	MS	P > F
Y	1	6.26	
I	2	0.38	0.50
Y x I	2	0.31	0.01
T	3	0.40	(0.01)[b]
I x T	6	0.17	(0.01)
Y x T	3	0.01	n.s.[c]
Y x I x T	6	0.01	n.s.
ML	1	3.43	(0.01)
Y x ML	1	0.00[d]	n.s.
I x ML	2	0.34	(0.01)
T x ML	3	0.54	0.20
Y x I x ML	2	0.01	n.s.
Y x T x ML	3	0.12	0.03
I x T x ML	6	0.22	(0.01)
Y x I x T x ML	6	0.04	0.27
Error	68		

[a]Y = years, I = inbred parents, T = drying temperatures, and ML = the linear component of moisture.

[b]( ) tested with pooled error.

[c]Nonsignificant at the 0.50 level.

[d]MS < 0.01.

Table 12. Mean predicted values for seed quality measurements for A632, B73, and Mo17

Quality measurement	Harvest moisture (%)	Maternal parent A632 Temperature (C) 50	45	40	35	CLM[a]
Germination (%)	45	87[b]	99	99	99	9
	40	88	99	99	99	7
	35	89	99	99	99	6
	30	91	99	99	99	6
	25	92	99	100	99	7
Cold-test emergence (%)	45	59	88	98	98	11
	40	63	89	98	98	9
	35	68	91	98	98	7
	30	73	92	98	99	7
	25	77	93	99	99	9
Seedling dry weight (mg/seedling)	45	41	48	54	55	9
	40	45	51	56	56	8
	35	49	54	57	57	6
	30	53	57	58	58	6
	25	57	60	59	59	7
Ratio[c]	45	1.48	1.53	1.50	1.61	0.32
	40	1.42	1.48	1.45	1.54	0.25
	35	1.36	1.44	1.40	1.46	0.22
	30	1.29	1.39	1.35	1.39	0.22
	25	1.23	1.34	1.30	1.31	0.27

[a]95% confidence limits for mean predicted values within a maternal parent and harvest moisture.

[b]Regression equations for these predicted values are given in Appendix B.

[c]Ratio of root to shoot dry weight.

Maternal parent									
B73					Mo17				
Temperature (C)					Temperature (C)				
50	45	40	35	CLM	50	45	40	35	CLM
41	92	99	100	9	45	89	97	98	9
57	95	99	100	6	56	91	96	97	7
72	98	99	100	6	67	93	96	97	6
88	101	99	99	7	78	95	95	96	6
103	103	99	99	10	89	97	95	96	9
4	75	98	99	11	7	49	88	96	11
20	80	98	99	8	22	58	89	96	8
37	84	99	99	7	38	67	90	96	7
53	89	99	99	9	54	76	91	96	8
69	94	99	98	13	70	85	92	95	11
30	39	49	52	8	31	41	53	58	9
37	44	52	54	7	36	44	54	58	7
43	49	55	57	6	41	48	55	58	6
50	54	58	59	6	46	52	57	59	6
56	60	61	61	8	51	55	58	59	7
2.47	1.76	1.46	1.34	0.31	1.92	1.71	1.21	1.24	0.32
2.07	1.61	1.39	1.30	0.23	1.69	1.53	1.18	1.20	0.24
1.68	1.45	1.32	1.27	0.20	1.47	1.35	1.15	1.17	0.21
1.29	1.30	1.25	1.23	0.27	1.23	1.17	1.13	1.13	0.24
0.90	1.14	1.18	1.20	0.37	1.01	0.99	1.10	1.09	0.32

Table 13. Analyses of variance for seed quality measurements for B37

Quality measurement	Source of variation[a]	d.f.	MS	P > F
Germination (%)	M	4	250.55	0.02
	M (linear)	1	602.85	0.01
	T	3	1397.25	0.01
	M x T	12	241.41	0.01
	M (linear) x T	3	471.93	0.01
	Error	60	79.55	
Cold-test emergence (%)	M	4	2376.64	0.01
	M (linear)	1	5277.33	0.01
	T	3	11155.42	0.01
	M x T	12	1091.38	0.01
	M (linear) x T	3	2724.83	0.01
	Error	60	127.71	
Seedling dry weight (mg/seedling)	M	4	364.52	0.01
	M (linear)	1	1218.41	0.01
	T	3	832.53	0.01
	M x T	12	109.83	0.01
	M (linear) x T	3	400.20	0.01
	Error	60	36.25	
Ratio[b]	M	4	0.51	0.01
	M (linear)	1	1.23	0.01
	T	3	0.36	0.03
	M x T	12	0.08	n.s.[c]
	M (linear) x T	3	0.13	0.40
	Error	60	0.11	

[a]M = harvest moisture and T = drying temperature.

[b]Ratio of shoot to root dry weight.

[c]Nonsignificant at the 0.50 level.

M(linear) by T interactions for ratio, all other components for all B37 quality measurements were significant at the 0.01 level. Coefficients of determination (r^2 values) for the models used to predict the values shown in Table 14 were 0.48, 0.74, 0.66, and 0.22 for germination, cold-test emergence, seedling dry weight and ratio respectively.

Exhaustion tests

Mean results from the exhaustion tests are presented in Table 15. In general, few differences due to harvest moisture or drying temperatures were apparent. However, striking differences were found for seed of Mo17 that was harvested at 39% moisture and dried at 50 C. Compared with other treatments, almost twice as much of the original kernel dry weight still remained in the seed after the 18-day grow out period. This decrease in kernel catabolism was, in turn, reflected by a reduction in root weight. Only 12% of the original kernel dry weight was transferred to roots, compared to 20-22% root transfer for other Mo17 treatments. Shoot transfer was unaffected.

Effect of temperature without drying

Results obtained from standard germination tests on seed which had been exposed to temperatures of 35 or 50 C, for 3, 6, or 12 hours, without drying, are given in Table 16. The 10 C control and 35 C treatments showed relatively high germination percentages, regardless of harvest moisture or time of exposure, for all three maternal parents. At 50 C, marked declines in germination were recorded after seed was exposed for 3, 6, or 12 hours at earlier harvests. However, as harvest moisture

Table 14. Mean predicted values for seed quality measurements for B37

Quality measurement	Harvest moisture (%)	Temperature (C)				CLM[a]
		50	45	40	35	
Germination (%)	45	69[b]	98	99	99	7
	40	76	98	99	100	5
	35	82	99	99	100	4
	30	89	99	100	100	5
	25	96	99	100	100	7
Cold-test emergence (%)	45	16	75	99	99	11
	40	32	80	99	99	8
	35	49	85	99	99	7
	30	65	90	99	99	8
	25	81	96	99	99	11
Seedling dry weight (mg/seedling)	45	34	50	57	62	4
	40	40	53	59	61	3
	35	47	56	61	61	3
	30	53	59	63	60	3
	25	59	62	64	59	4
Ratio[c]	45	1.77	1.77	1.59	1.50	0.18
	40	1.69	1.69	1.50	1.42	0.16
	35	1.60	1.60	1.42	1.34	0.15
	30	1.52	1.52	1.34	1.25	0.15
	25	1.44	1.44	1.26	1.17	0.18

[a]95% confidence limits for mean predicted values within a harvest moisture.

[b]Regression equations for these predicted values are given in Appendix B.

[c]Ratio of shoot to root dry weight.

Table 15. Effect of drying temperature and harvest moisture on dry weight conversion to shoot and root development for three maternal parents

		Maternal parent	
		A632	
		Drying temp. (C)	
Original dry weight	Harvest moisture (%)	35	50
Remaining in kernel (%)	43	14[a]	15
	34	14	17 (2)
Converted to shoots (%)	43	31	29
	34	29	28
Converted to roots (%)	43	17	15
	34	17	16

[a]Values are means from ten rolled towels.

[b]( ) standard errors for those mean values. Where no parentheses appear, standard errors were less than or equal to 1.

Maternal parent					
B73			Mo17		
Harvest moisture (%)	Drying temp. (C) 35	Drying temp. (C) 50	Harvest moisture (%)	Drying temp. (C) 35	Drying temp. (C) 50
39	16	19	39	14	33 (5)[b]
36	16	20	36	14	17 (2)
39	28	26	39	25	24 (2)
36	25	24	36	25	26
39	18	17	39	22	12
36	19	17	36	22	20

Table 16. Effect of exposure to temperatures of 35 or 50 C, for 3, 6, or 12 hours, without drying, on germination of A632, B73, and Mo17 harvested at different moisture contents

			Temperature exposure (C)[a]		
			35		
			Time in hours		
Maternal parent	Harvest moisture (%)	10 C control	3	6	12
A632	52	100[b]	100	99	100
	32	99	98 (2)	100	100
	18	99	100	99	100
B73	47	100	92 (2)	100	100
	35	100	100	100	100
	28	100	100	100	100
Mo17	49	90 (2)	100	97 (3)	99
	34	100	99	100	100
	25	100	99	99	100

[a]After exposure to temperatures of 35 or 50 C for 3, 6, or 12 hours, ears were unwrapped and dried to approximately 12% moisture at 10 C.

[b]Values are means from two 50-seed replicates.

[c]( ) standard errors for those mean values. Where no parentheses appear, standard errors were less than or equal to 1.

Temperature exposure (C)		
50		
Time in hours		
3	6	12
76	26 (2)[c]	0
100	94	11 (3)
100	100	99
100	5 (3)	0
99	74 (4)	0
99	100	33 (5)
66	0	0
90	27	0
99	99	99

decreased, seed from all three maternal parents showed less susceptibility to 50 C exposures up to 12 hours in length.

Rate of drying

Drying rate data given in Table 17 are slopes from regressions of seed moisture on drying time. The field drying slopes were derived from the harvest data (Table 2).

At 35 C, A632 lost moisture at approximately 0.46 percentage points per hour compared with Mo17 at 0.41 percentage points per hour and B73 at 0.30 percentage points per hour. The ranking of A632 greater than Mo17 and greater than B73 was consistent for all drying temperatures except 35 C where little difference existed. Field drying rates showed a similar ranking.

Effect of overdrying

Table 18 reports the final moisture content of seed, from inbred parent Mo17, that were overdried at four harvests in 1980. Due to the uniform seven-day drying period, final moistures varied with harvest moisture and drying temperature. As drying temperature decreased and/or harvest moisture increased, final harvest moistures were generally higher.

Analyses of variance for seed quality measurements for the overdrying study are given in Table 19. The T by drying treatment (D) interactions were significant at the 0.01 level for both germination and cold-test. Drying treatments were significant at the 0.05 and 0.01 levels for germination and cold-test emergence respectively. Contrasts of seed dried to 12% moisture, and seed that were overdried and equilibrated, with

Table 17. Drying rate of three maternal parents at four drying temperatures and in the field in 1980

Maternal parent	Harvest moisture (%)	Laboratory drying[a] Drying temperature (C) 50	45	40	35	Field drying[b]
A632	52	0.73[c]	0.57	0.56	0.46	1.02
B73	47	0.47	0.52	0.39	0.30	0.70
Mo17	49	0.60	0.58	0.35	0.41	0.79

[a]Percentage points per hour.

[b]Percentage points per day.

[c]Unreplicated data.

Table 18. Final moisture content of seed of maternal parent Mo17 overdried at four drying temperatures

1980 harvest moisture (%)	Drying temperature (C)				Row means
	50	45	40	35	
36	5	7	8	9	7
34	6	7	8	10	8
29	5	5	6	8	6
25	4	5	6	7	5
Column means	5	6	7	8	

Table 19. Analyses of variance for quality measurements of Mo17 overdried in 1980

Quality measurement	Source of variation[a]	d.f.	MS
Germination (%)	M	3	(5297.24)[b]
	T	3	(16853.46)
	M x T	9	(2770.72)
	D	2	228.39*
	D1	1	6.12
	D2	1	450.67*
	M x D	6	87.78
	T x D	6	574.34**
	M x T x D	18	66.43
	Error	144	71.37
Cold-test emergence (%)	M	3	(9940.14)
	T	3	(31582.56)
	M x T	9	(1499.69)
	D	2	885.22**
	D1	1	82.88
	D2	1	1687.57**
	M x D	6	35.51
	T x D	6	154.98
	M x T x D	18	103.13
	Error	144	121.89
Seedling dry weight (mg/seedling)	M	3	(1697.97)
	T	3	(3493.15)
	M x T	9	(255.08)
	D	2	188.13
	D1	1	239.19
	D2	1	137.08
	M x D	6	73.21
	T x D	6	274.45**
	M x T x D	18	81.02
	Error	144	73.06

[a]M = harvest moisture, T = drying temperature, D = drying treatment, D1 = dried to 12% versus overdried and equilibrated, D2 = dried to 12%, and overdried and equilibrated versus overdried and not equilibrated.

[b]No test of significance was made.

*,**Significant at the 0.05 and 0.01 levels, respectively.

Table 19. (Continued)

Quality measurement	Source of variation	d.f.	MS
Ratio[c]	M	3	(0.55)
	T	3	(0.13)
	M x T	9	(0.18)
	D	2	0.07
	D1	1	0.07
	D2	1	0.07
	M x D	6	0.03
	T x D	6	0.10
	M x T x D	18	0.07
	Error	144	0.06

[c]Ratio of shoot to root dry weight.

seed that were overdried and not equilibrated, were also significant at the 0.05 and 0.01 levels for germination and cold-test emergence respectively.

Germination, cold-test emergence, and seedling dry weight results from the overdrying study are presented in Table 20. L.S.D. values, calculated using the error mean square are also given. At drying temperatures up to 45 C, seed equilibrated from the overdried condition to approximately 11% moisture elicited the same general responses as were obtained from seed removed at 12% moisture initially. However, germination of seed dried to 12% moisture at 40 C and seedling dry weight of seed dried to 12% moisture at 35 or 40 C, exhibited lower performances than their overdried counterparts. Although germination and cold-test emergence percentages were lower for seed overdried at 50 C and equilibrated than for seed dried to 12%, only the difference in germination was statistically significant.

Seed that was overdried at 35 or 40 C and maintained in that condition elicited the same general responses as were obtained from seed that had been overdried and equilibrated. However, seed that was overdried at 45 C and maintained in that state, showed a significant decline in cold-test emergence. Seed that was overdried at 50 C showed marked reductions for all three quality parameters.

Field Emergence

Analyses of variance for 1980 field emergence of A632, B37, B73, and Mo17 are given in Table 21. Planting dates (P), M by P, T by P, and

Table 20. Effect of different drying temperatures and drying treatments on germination, cold-test emergence, and seedling dry weight

Quality measurement[a]	Drying treatment	Drying temperature (C)				Row means
		50	45	40	35	
Germination (%)	Dried to 12%	68	94	92	95	87
	Overdried and equilibrated	58	95	98	96	87
	Overdried and not equilibrated	48	93	98	97	84
Cold-test emergence (%)	Dried to 12%	42	73	87	93	74
	Overdried and equilibrated	35	74	86	93	72
	Overdried and not equilibrated	28	64	84	90	67
Seedling dry weight (mg/seedling)	Dried to 12%	53	55	61	63	62
	Overdried and equilibrated	50	59	69	68	59
	Overdried and not equilibrated	42	55	67	69	58

[a]Values are means of four harvests. L.S.D. 0.05 = 6 for germination, 8 for cold-test emergence, and 6 for seedling dry weight.

Table 21. Analyses of variance for 1980 field emergence of maternal parents A632, B37, B73, and Mo17.

Maternal parent	Source of variation[a]	d.f.	MS
A632	M	3	(151.76)[b]
	T	3	(740.42)
	M x T	9	(188.29)
	B (P)	6	6.43
	P	1	599.45**
	M x P	3	132.86**
	T x P	3	65.95**
	M x T x P	9	23.42**
	Error	90	7.21
B37	M	4	(1959.66)
	T	3	(6847.87)
	M x T	12	(1025.28)
	B (P)	6	4.19
	P	1	2212.66**
	M x P	4	275.50**
	T x P	3	302.41**
	M x T x P	12	43.96**
	Error	114	12.69
B73	M	4	(4409.33)
	T	3	(5335.12)
	M x T	12	(1273.55)
	B (P)	6	43.63*
	P	1	4060.22**
	M x P	4	408.58**
	T x P	3	677.94**
	M x T x P	12	89.28**
	Error	114	16.48

[a]M = harvest moisture, T - drying temperature, B - blocks, P = planting dates.

[b]( ) no test of significance was made.

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Table 21. (Continued)

Maternal parent	Source of variation	d.f.	MS
Mo17	M	4	(4967.90)
	T	3	(10042.71)
	M x T	12	(1934.74)
	B (P)	6	26.46
	P	1	3195.16**
	M x P	4	332.55**
	T x P	3	205.64**
	M x T x P	12	77.76**
	Error	114	16.89

M by T by P were all significant at the 0.01 level for all maternal parents. Blocks within P were significant at the 0.05 level for B73 only.

Field emergence means are presented in Table 22. Little difference in planting dates was observed with lower harvest moistures and/or drying temperatures for all maternal parents. However, at higher harvest moistures and/or drying temperatures, field emergence percentages decreased, with the magnitude of those decreases being greater for the 1 May date of planting. Anomalous declines in germination and cold-test emergence for A632 harvested at 34 and 31% moisture and for B37 harvested at 40% moisture were still evident.

Table 22. Mean field emergence of four maternal parents harvested at different moisture contents, dried at different drying temperatures, and planted on 1 May and 23 May 1980

		Planting date							
		1 May 1980				23 May 1980			
		Drying temperature (C)				Drying temperature (C)			
Maternal parent[a]	Harvest moisture (%)	50	45	40	35	50	45	40	35
A632	43	84	77	92	94	96	96	96	99
	34	77	96	97	98	80	99	97	98
	31	79	93	97	97	87	97	99	97
	19	95	96	98	95	97	98	97	98
B37	45	43	76	90	95	66	95	96	98
	40	26	72	91	94	51	91	98	98
	36	55	89	96	93	69	96	99	95
	29	87	95	96	95	94	95	97	96
	24	94	96	96	95	97	95	96	97
B73	47	13	32	85	93	45	67	97	97
	39	59	73	91	95	79	93	97	98
	36	64	92	97	95	91	98	98	96
	31	78	93	96	96	94	97	96	99
	25	91	93	92	96	96	96	95	95
Mo17	47	10	37	83	93	37	68	95	98
	39	23	70	95	93	40	88	98	99
	36	75	78	95	95	79	90	99	98
	30	76	92	97	97	84	95	96	99
	23	93	96	93	86	98	98	97	97

[a]L.S.D. 0.05 = 4, 5, 6, and 6 for A632, B37, B73, and Mo17, respectively.

DISCUSSION

Data presented in Table 7 indicate that simple correlations between maturity indices and seed quality parameters, across genotypes and/or drying temperatures, do not exist. Therefore, the low P > F values, reported for the I by T by ML interactions in Tables 8-11, could have been expected. Those interactions alone do not allow for simple recommendations of harvest moistures and drying temperatures.

Predicted values, given in Tables 12 and 14 summarize the data and generally serve to more clearly describe differences in dryer tolerance between inbred parents. With the exception of A632 and B37 dried at higher temperatures, those predicted values should give seed producers an idea of the quality responses they could expect from seed of A632, B37, B73, or Mo17 harvested at different moisture contents and dried at different drying temperatures. However, low coefficients of determination, from the models used to predict values for the A632, B73, and Mo17 seedling dry weight and ratio variables, indicate that more caution should be exercised in the application of those predicted values. Further, the fact that predicted values for B37 are based on only one year of data demands that they also be applied conservatively.

Cold-test emergence proved to be the most responsive quality measurement that was studied. If an 80% cold-test emergence is chosen as the lowest acceptable level for marketable seed performance, the predicted values indicate that seed from maternal parent Mo17 should not normally be dried at temperatures as high as 45 C unless harvest moistures are 25% or below. Given the same criteria of acceptability, B73 could be dried at temperatures up to 45 C at harvest moistures up to 40%.

The anomalous declines already noted for A632 and B37 germination and cold-test emergence make reliable high temperature drying recommendations difficult for those maternal parents. Washko (24) reported a similar response with inbred line R3. At a drying temperature of 52 C, he observed that seed harvested at 44% moisture was heat tolerant whereas seed harvested at 32% moisture showed injury. Comparable declines were not clearly observed with B73 and Mo17 in this study. Therefore, it is possible that such responses are only associated with maternal parents that are relatively tolerant of high drying temperatures. Struve (23), using combinations of slow and rapid drying methods, reported that the amount of damage incurred was a function of the drying rate over critical moisture levels, particularly between 40 and 30% moisture. The results of Burris and Navratil (3) indicated a relationship between damage severity and drying temperature when seed from maternal parent Mo17 passed between 40 and 30% moisture. Although it is not clear whether the findings of Struve, or Burris and Navratil, are related to those reported here and by Washko, the fact that these responses were observed over the moisture range where most seed corn is harvested makes further investigation crucial.

Although the ratio variable presented in Tables 3-6, and its predicted values given in Tables 12 and 14, are probably of little applied value, they help to describe the extent of the damage caused by drying. The occurrence of higher ratio values, associated with reduced germination and cold-test emergence percentages, indicates that root development is more susceptible to injury than is shoot development. Results from the exhaustion tests (Table 15), particularly Mo17 dried at 50 C, show that higher ratio values are a result of decreased transfer of original kernel weight to roots only. Shoot transfer was unaffected. Casual observations in these studies suggested that primary root development was depressed or nonexistent in seed samples that showed injury. Such observations would corroborate the histological observations of Washko (24). He proposed a relationship between drying damage and disintegration of the meristematic cells of the primary root.

Previous studies have not separated drying rate from drying temperature. To determine if dryer-induced injury was primarily a result of high drying temperatures, or faster drying rates associated with higher drying temperatures, the effect of temperature without drying was studied. The results (Table 16) do not rule out an effect due to rate of drying. However, although they may be confounded by microbial contamination, the magnitude of the 50 C responses indicate that drying temperature is probably responsible for most, if not all, of the injury observed in these studies.

A preliminary comparison of drying rates among A632, B73, and Mo17 (Table 17) generally showed that A632, the heat tolerant genotype, dried at the fastest rate in both the laboratory and the field. Faster drying rates have been associated with thinner pericarps (20) and endosperm types low in hydrophilic compounds (16). Because of the limited cross section in this study, it would be premature to suggest that tolerant genotypes may be able to dissipate moisture at a greater rate than do intolerant genotypes. However, failure to dissipate moisture would result in prolonged exposure to high temperatures at high seed moistures. A greater rate of moisture dissipation could result in increased evaporative cooling which may keep the seed cooler during a critical drying period. If tolerant genotypes are, in fact, able to dissipate moisture at a greater rate, then it is possible that tolerant lines could be selected using field drying rates. This will require considerably more investigation.

Overdrying down to four percent moisture, at nonharmful temperatures, has not been shown to effect seed quality (10, 11). Results from this study generally confirm those findings (Table 20). Seed overdried at 35 or 40 C exhibited high quality responses whereas seed overdried at 45 or 50 C, and maintained in that condition, did not perform as well as seed that had been dried to 12% moisture initially. Differences were noted, in germination and cold-test emergence percentages, between seed dried to 12% moisture at 50 C and seed that was overdried at the same temperature and subsequently equilibrated. Such differences are probably due to injury caused by the use of higher drying temperatures.

Cal and Obendorf (5) reported that low kernel moisture in both the hybrid W153r x Pa33 and its maternal parent, was detrimental to radical growth when germinated at 25 C. Germination at 5 C magnified that response. Other genotypes, such as the hybrid (Oh51a x B8) x NY821, showed injury when low moisture (6%) kernels were imbibed at 5 C but not at 25 C. Nutlie (19), working with sorghum (Sorghum vulgare Pers.), overdried to three percent moisture, suggested that injury during germination was due to an abnormally rapid uptake of water by the dried embryo. Differences observed between seed that was overdried at higher temperatures and maintained in that condition, and seed that was overdried at those temperatures and subsequently equilibrated, could therefore be due to injury resulting from an abnormally rapid uptake of water and the lesion formation associated with that water uptake.

Final moisture contents of seed overdried at 35 and 40 C were not as low as were final moisture contents of seed overdried at 45 and 50 C (Table 18). In contrast to studies where no effect associated with overdrying at nonharmful temperatures was shown (10, 11), the findings of Nutlie (19) and Cal and Obendorf (5) suggest that if the seed overdried at 35 and 40 C had been dried further, an effect due to overdrying might have been shown. However, such a response may be genotype specific.

Field emergence of 1979 seed planted in 1980 was in general agreement with the germination and cold-test emergence percentages (Table 22). Results from the 1 May field planting were comparable to the cold-test whereas the 23 May field planting approximated a germination test. No unexpected or unexplainable responses were observed. Because the anomalous declines noted for A632 and B37 in the laboratory tests were still apparent seven months after harvest, those responses are most likely a result of permanent dryer injury. Casual observations of plant growth in the field generally showed responses similar to those exhibited by seedling growth in the laboratory. At 32 days after the 23 May planting date, striking treatment differences were still visible.

Seed moisture content was used as an index of maturity for these studies. In spite of the climatological differences between 1979 and

1980 (Table 1), seed quality measurements were quite comparable over the two years. However, that consistency does not guarantee that seed moisture is a dependable index of maturity within or even across genotypes. Shaw and Thom (22) reported large differences in moisture percentage, at the time of physiological maturity, among hybrids in any one year and for individual hybrids in different years. It is therefore possible that environmental conditions during maturation could alter moisture content without altering some physiological parameter associated with dryer-induced injury, or vice versa.

The results of Burris and Navratil (3) suggested a possible relationship between dryer-induced injury and increased susceptibility to imbibitional chilling injury. Inasmuch as imbibitional chilling injury has been attributed to faulty membrane reorganization (2), the expression of dryer injury may be a consequence of permanent membrane damage.

A sequencing study, involving the transfer of seed from 35 to 50 C, and vice versa, could be helpful in determining when seed injury occurs. Seed from such a study could then be subjected to electron microscopy to better describe physical changes associated with dryer-induced injury. Conductivity testing may provide another estimate of overall seed integrity. A632, the tolerant genotype in this study, exhibited a faster rate of drying. If several genotypes were screened for tolerance to dryer-induced injury, monitoring seed temperatures during such screening would indicate if faster drying rates, dryer tolerance, and lower seed temperatures are related.

Finally, certain physiological parameters could be monitored during maturation and mechanical drying to see if any relationships with dryer-induced injury are apparent. Enzyme activities, sugar analyses, and hormone levels could be studied. Although correlation would not imply causation, such studies may be helpful in determining the physiological basis of dryer injury. It is clear from these studies that certain maternal parents are more tolerant of dryer-induced injury than others. However, the basis for those differences is not understood. Only gross measurements of seed quality have been provided here. A more complete understanding of the physiological basis of dryer-induced injury would be desirable to maximize drying efficiency while minimizing potential damage.

SUMMARY AND CONCLUSIONS

Four of the most widely grown public corn inbreds were tested for tolerance to dryer induced injury. Inbred parent B37 was grown in 1979, and A632, B73, and Mo17 were grown in 1979 and 1980. The single cross H99 x H95 was used as a pollinator both years. Random ear samples were then collected to obtain ears with moisture percentages ranging from approximately 50 to 20%, and dried to 12% moisture at 35, 40, 45, and 50 C.

Inbred parents were found to differ in tolerance to high drying temperatures. A632 showed the most tolerance to high drying temperatures while B73 and Mo17 proved to be relatively intolerant. Based on only one year of data, B37 was intermediate in tolerance.

Combined analyses yielded significant inbred-parent by harvest-moisture by drying-temperature interactions for germination and cold test emergence percentages. Those interactions alone do not allow for simple recommendations of safe harvest moistures and drying temperatures.

A preliminary comparison of drying rates among inbred parents A632, B73, and Mo17 generally showed that A632, the tolerant genotype, dried at the fastest rate in both the laboratory and the field. Although it would be premature to suggest that tolerant genotypes may be able to dissipate moisture at a greater rate than do intolerant genotypes, failure to dissipate moisture would result in prolonged exposure to high temperatures at high seed moistures.

The data indicated that overdrying at high temperatures may have detrimental effects on seed quality. However, the performance of seed overdried at 35 or 40 C, and maintained in that state, was comparable to seed that had been dried to 12% moisture.

A study of dry matter transfer from kernels to shoots and roots showed that root growth of intolerant genotypes was more susceptible to drying injury than was shoot growth. Casual observations indicated that reduced transfer to roots was associated with little or no primary root development.

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APPENDIX A. SMALL-SCALE DRYER DESIGN

R. J. Navratil and J. S. Burris

Four small-scale, single-pass movable dryers were constructed in 1979. They each consist of a cap, stackable trays, and a base built on four 10.2-cm-diameter casters (Figure A1).

Each base, 61.0 cm x 61.0 cm x 61.0 cm, (Figure A2) houses four 30.5-cm, 240-V 750-W Chromalox[1] OTF strip heaters with lock-on fins. The heaters were mounted under a flat piece of galvanized steel to prevent debris from sifting down on top of the elements.

Heat output was controlled with AR-2524 Chromalox industrial thermostats, which have a temperature range of 10 to 121 C ± 3.1. Thermostat controls, along with 110-V relays, were mounted on the outside of each base. A 2.1-m capillary tube allowed the sensing bulb to be placed behind the heater mount within each base. Temperatures were monitored hourly with use of a 24-point potentiometric recorder and copper-constantan thermocouples with error limits of ± 1.0 C.

A centrifugal fan, powered by a 1/3-hp, 115-V motor capable of moving up to 196 L/s at 7.6 cm static pressure, also was mounted on each base. Fan discharge was across the heating elements. Airflow can be adjusted by use of a slide gate attached to the fan intake.

The base units also served as plenums for mixing the air. To obtain

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[1]Mention of a company name or trademark is for the reader's benefit and does not constitute endorsement of a particular product over others that may be commercially available.

Figure A1. One drying unit with five stackable trays; A. thermostat control B. fan C. exhaust port D. slide gate

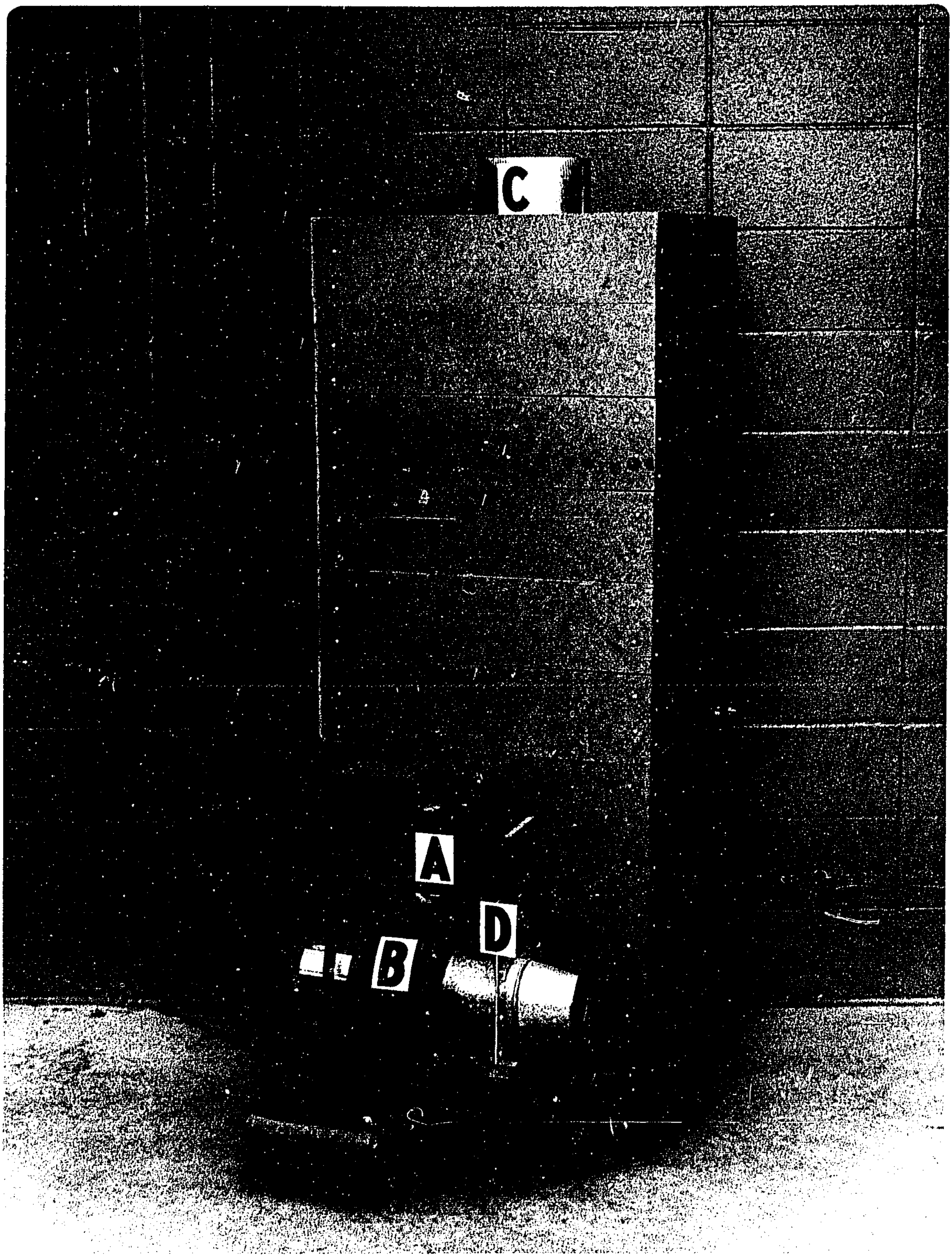
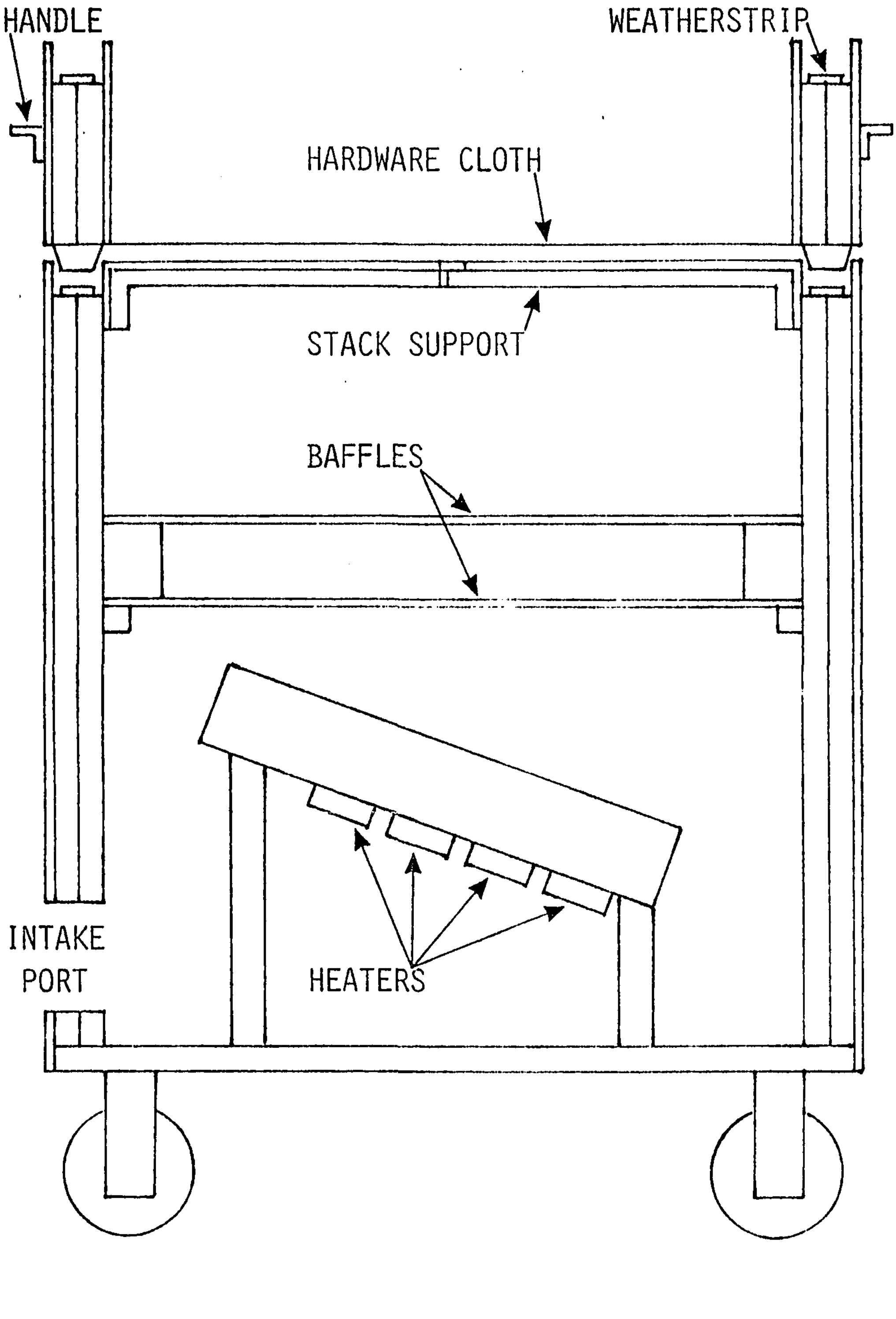

C
A
D
B

Figure A2. Cross section of a base and one stackable tray without dividers


HANDLE
WEATHERSTRIP
HARDWARE CLOTH
STACK SUPPORT
BAFFLES
INTAKE
PORT
HEATERS

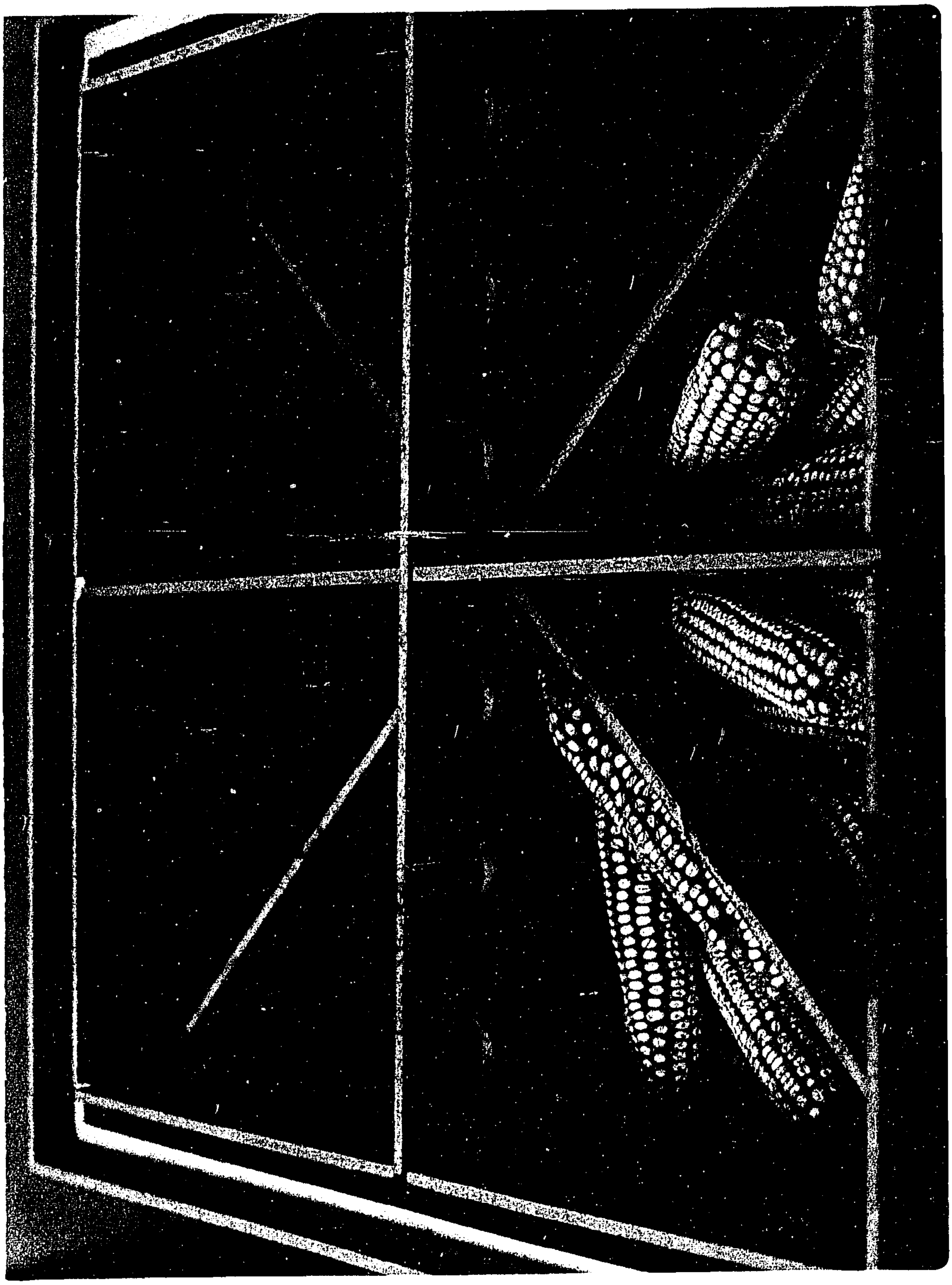
uniform airflow into each stack, two baffle sheets of 0.6-cm hardboard were installed in the upper half of each base. A 3.8-cm hole was drilled in the center of each quarter of the lower sheets. Upper sheets had 0.6-cm holes drilled on 2.5-cm centers.

Base walls consisted of a 1.9-cm layer of styrofoam sandwiched between an outer layer of hardboard and an inner layer of 1.9-cm plywood. The floor was a single sheet of plywood. Cross supports for the stacks were fashioned out of 1.9 x 0.3 cm steel angle and were bolted at the top of the base walls.

With the addition of another layer of hardboard on the inside, the trays, 61.0 cm x 61.0 cm x 15.2 cm, utilize a sandwich construction similar to that used for the base. The bottoms are 0.3-cm hardware-cloth, which is attached to the sandwich sides with 3.8 cm x 1.9 cm wooden strips. The strips were tapered to 2.5 cm at the bottom. The tapered strips fit into 3.8 cm x 2.5 cm grooves, which have been made on the top of the trays and bases. With the addition of 1.9 cm x 0.6 cm weather stripping in the grooves, a relatively airtight stacking can be achieved. Handles on opposite sides of the trays made from 2.5 cm x 0.3 cm angle with two 0.8-cm holes drilled in each handle facilitate stacking and unstacking either manually or with use of an electric hoist and hooks.

The trays are subdivided with hardboard dividers into four main compartments that may be subdivided further (Figure A3). The main dividers are flush with the top of each tray to give internal support to the hardware-cloth bottoms down to the stack support in the base. Twelve 2.9-cm holes per tray were drilled near the top of the main dividers to facilitate

Figure A3. Tray showing main and secondary dividers



air movement throughout the stack.

To maintain turbulence in the stack 5.1-cm-wide duct tape was affixed to the hardware cloth under the main dividers, and 2.5-cm-wide duct tape was affixed around the edges of the tray bottoms.

The cap, 61.0 cm x 61.0 cm x 15.2 cm, also of sandwich construction, had a plywood top with a 19.7-cm-diameter exhaust port. Exhaust air was vented to the outside to maintain ambient room air at a relatively constant temperature.

The four dryer units were operated in 1979 and 1980 at 35, 40, 45 or 50 C. Ambient air was relatively constant at 22 ± 1 C. Ambient relative humidity was monitored with a hydrothermograph in 1980 and was found to be 45 ± 5%. No determinations of relative humidity were made in 1979. Four stackable trays and eight stackable trays per unit were used in 1979 and 1980 respectively. Airflow rates of 1.3 and 18.4 $L/s/m^2$ were used in 1979 and 1980, respectively, depending on the stack height, to obtain greater uniformity throughout the stack.

In 1979, 10 ears were placed in each main section of the trays, with a total of 40 ears per tray. Subdividers were used in 1980 (Figure A3), and 6 ears were placed in each subdivision in the bottom 5 trays, with a total of 48 ears per tray. The upper 3 trays were loaded with 80 ears per tray.

Table A1 shows the measured temperatures in the dryers in 1979 and 1980 at the bottom, just below the first tray of corn, and at the top, in the exhaust port. In both years, some temperature drop occurred from the bottom to the top. Because a drop of 1 C or less has been noted when the

Table A1. Drying temperature data for 1979 and 1980

		Desired temperature °C			
		50		45	
Year	Thermocouple position	Mean	Standard deviation	Mean	Standard deviation
1979	Top[a]	48.0	1.0	44.4	0.7
	Bottom	52.2	1.5	45.7	0.9
	Mean	50.1	1.2	45.1	0.8
1980	Top	48.6	1.8	44.7	0.4
	Bottom	50.9	1.8	45.8	0.7
	Mean	49.7	1.7	45.2	0.5

[a]Top was measured in the exhaust port and bottom was measured just below the first tray. Mean is the mean of the top and bottom observations averaged together. n = 25 measurements taken at random from the 1979 or 1980 data.

Desired temperature			
40		35	
Mean	Standard deviation	Mean	Standard deviation
39.5	1.0	34.3	0.7
40.8	1.6	36.1	1.4
40.2	1.2	35.1	0.7
39.7	0.7	34.7	1.4
40.5	0.9	35.1	1.6
40.1	0.7	34.9	1.5

dryers have been operated without corn, evaporative cooling probably accounts for the temperature drop. Inasmuch as all seed in a thin-layer drying system are, in theory, exposed to air of uniform temperature and humidity, the evaporative cooling noted here would indicate a small departure from the thin-layer concept.

In spite of the increased height of the stack, which allowed more ears to be dried in 1980, the two years are quite comparable in temperature differential from bottom to top and in variability as indicated by the standard deviations. Increased airflow in 1980 evidently helped prevent excessive cooling. Measured mean temperatures in both years were within 0.3 C of the desired temperatures.

The fans described here are capable of drying shell corn or bulk beans as well as ear corn. By connecting the exhaust ports of adjacent stacks, these units could also be converted to a two-pass system. They easily lend themselves to drying research and could be used to screen germplasm for tolerance to high drying temperatures.

APPENDIX B. REGRESSION EQUATIONS FOR MEAN PREDICTED VALUES

Table B1. Regression equations used to derive mean predicted values for seed quality measurements for four maternal parents

Maternal parent	Temperature (C)	Independent variable	
		Germination (%)	Cold-test emergence (%)
A632	50	= 98.56 - 0.26 (M)[b]	= 99.68 - 0.91 (M)
	45	= 99.81 - 0.02 (M)	= 100.25 - 0.28 (M)
	40	= 100.53 - 0.03 (M)	= 99.88 - 0.05 (M)
	35	= 99.14 + 0.01 (M)	= 100.73 - 0.07 (M)
B37[c]	50	= 128.88 - 1.33 (M)	= 186.21 - 3.79 (M)
	45	= 100.22 - 0.04 (M)	= 121.40 - 1.03 (M)
	40	= 101.86 - 0.07 (M)	= 98.86 - 0.01[d] (M)
	35	= 99.95 - 0.01 (M)	= 99.45 - 0.01[d] (M)
B73	50	= 180.49 - 3.09 (M)	= 151.27 - 3.27 (M)
	45	= 117.74 - 0.57 (M)	= 116.53 - 0.92 (M)
	40	= 98.58 + 0.02 (M)	= 99.11 - 0.02 (M)
	35	= 98.96 + 0.02 (M)	= 98.41 + 0.01[e] (M)
Mo17	50	= 144.51 - 2.22 (M)	= 149.84 - 3.18 (M)
	45	= 106.32 - 0.39 (M)	= 130.02 - 1.80 (M)
	40	= 92.87 + 0.09 (M)	= 98.03 - 0.23 (M)
	35	= 93.84 + 0.08 (M)	= 94.57 + 0.03 (M)

[a]Ratio of shoot to root dry weight.

[b](M) = harvest moisture.

[c]B37 equations based on one year of data, all others over two years.

[d]Value less than -0.01.

[e]Value less than 0.01.

Independent variable	
Seedling dry weight (mg/seedling)	Ratio[a]
= 77.27 - 0.80 (M)	= 0.92 + 0.01 (M)
= 74.82 - 0.58 (M)	= 1.09 + 0.01 (M)
= 65.33 - 0.24 (M)	= 1.05 + 0.01 (M)
= 54.73 + 0.15 (M)	= 0.93 + 0.02 (M)
= 91.23 - 1.27 (M)	= 0.51 + 0.03 (M)
= 77.36 - 0.62 (M)	= 1.09 + 0.01 (M)
= 72.84 - 0.34 (M)	= 0.91 + 0.01 (M)
= 55.12 + 0.16 (M)	= 1.13 + 0.01 (M)
= 87.70 - 1.27 (M)	= -1.07 + 0.08 (M)
= 85.25 - 1.03 (M)	= 0.37 + 0.30 (M)
= 75.76 - 0.58 (M)	= 0.83 + 0.01 (M)
= 72.80 - 0.46 (M)	= 1.03 + 0.01 (M)
= 75.83 - 0.99 (M)	= -0.13 + 0.05 (M)
= 73.38 - 0.73 (M)	= 0.10 + 0.04 (M)
= 63.64 - 0.23 (M)	= 0.93 + 0.01 (M)
= 60.95 - 0.07 (M)	= 0.89 + 0.01 (M)