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THE EFFECT OF PACKAGING MATERIAL AND STORAGE
ON CORN SEED GERMINATION RATES

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THE EFFECT OF PACKAGING MATERIAL AND STORAGE ON CORN SEED GERMINATION RATES

By

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ABSTRACT

THE EFFECT OF PACKAGING MATERIAL AND STORAGE
ON CORN SEED GERMINATION RATES

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Donald L. Abbott

Hybrid corn seeds with a 98% certified germination rate were packaged in four different packaging materials and stored for a period of 18 months (two storage seasons) in an unconditioned shelter and also under controlled high temperature and high humidity conditions. Samples were tested for moisture, headspace gases, and germination rates at three month intervals. After 12 months of uncontrolled storage, the seed germination rates decreased and differences between the four packaging materials became apparent. The effect of package type on germination rates became more pronounced after 18 months. After 3 months of accelerated storage, all seeds were dead and this part of the study was discontinued.

After 18 months of storage, seed stored in plain paper bags decreased to 85.8% germination, seed in paper bags with a plastic inner liner decreased to 88.3% germination, seed in polyethylene bags decreased to 94.5% germination and seed in steel cans decreased to 96.5% germination.

DEDICATION

This thesis is dedicated to my parents, Gerald and Bertha Abbott.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and gratitude to:

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Marjorie, my wife, and my children who made this thesis possible and worthwhile.

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SYMBOLS AND TERMS

S.D. = Standard Deviation

Plastic = Low Density Polyethylene

Ave. = Average

INTRODUCTION

Corn is the only important cereal that evolved in the New World and is the leading cash crop in the United States (Chapman and Carter, 1976). It is the number one crop in the state of Michigan in both acreage and dollar value (Erdmann et al., 1981). Current United States' production is about 80,000,000 acres which require about 25,000,000 bushels of seed that must be harvested, stored, and packaged for the next planting season which could be several years later. The amount of extra (contingency) seed produced, but not sold, to assure market availability is unknown but significant.

Much is written about general seed storage conditions (Justice and Bass, 1978). All agree low seed moisture and low storage temperatures are ideal. Some information is available on packaging material selection (Copeland 1976), which shows moisture barrier materials are best, but most of these studies are based on small grass seeds and are in controlled environments. To date, nothing has been published about how the selection of a packaging material can influence hybrid corn seed stored in ambient conditions.

Interest in this study was a result of having personal daily contact with both agriculture and commercial packaging. This study is restricted to the comparison of a specific commercial hybrid seed that was sealed in four different packaging systems and stored for 18 months (two planting seasons). Random samples of each packaging system were fully tested every three months for changes. The storage conditions selected for this study were those that might be found in an unconditioned warehouse where daily temperature and relative humidity are constantly changing. Controlled storage conditions would have reduced seed deterioration but, from a commercial aspect, is costly and impractical and was not considered for this study. For testing, selected samples were subjected to package headspace gas measurements, seed moisture, and cold and warm germination testing.

Headspace gases measured were nitrogen, oxygen, and carbon dioxide, which would give an indication of seed respiration activity if the packaging material was of a suitable gas barrier. Only the steel cans had a measurable difference from normal atmospheric gas levels. Seed moisture gain or loss was measured to correlate seasonal humidity changes and packaging influences on seed protection. Seeds packaged in paper bags gained and lost significant moisture relative to seasonal relative humidity changes. Seeds packaged in paper bags with an inner plastic liner also gained or lost moisture, but to a lesser degree than did the paper only bags. Seeds in the plastic bags had a very small initial increase in moisture then remained quite stable for the remainder of the test period. Seeds packaged in steel cans did not show significant changes in moisture during this test period. Germination tests were conducted in accordance with "The Association of Official Seed Analysis Rules for Testing Seeds" and did show a germination difference corresponding to the different packaging materials.

LITERATURE REVIEW

Corn is a member of the grass family and is considered by many to be one of nature's most amazing energy storing devices. One small corn seed can turn into a 7 to 10 foot tall plant in just 9 weeks and some 8 weeks later will have produced up to 1,000 seeds (Aldrich, 1969).

Delorit (1974) claims that corn is the most valuable crop grown in the United States and that half of the world's crop is grown here. Most of the crop goes into livestock feed for meat and dairy production and some poultry and egg production. About 9% is used for human consumption in a variety of ways. At least 95% of the corn grown is the "dent" type, which can be grown in every state except Alaska. It ranks second to wheat in acreage of field crops in the world. Annual seed requirements for spring planting in the United States is about 2 million bags of 80,000 seeds each.

Authors of seed technology and seed research are in general agreement on storage conditions of common seeds. All state that low storage temperature and low seed moisture are the most important factors in maintaining high germination rates.

Cromarty (1982) classifies corn seed as "orthodox", where seed aging, which ultimately results in seed death, occurs as a function of time, temperature and moisture content. It is possible to influence the survival period by controlling the seed storage environment. The maximum longevity of seeds can be realized by storage at a low temperature and moisture content (down to 5% moisture).

Copeland (1976) states that this year's harvested seed crop would normally be planted 5 to 6 months later and the seeds are equipped to survive until the time and place are suitable for germination. Most species can survive storage much longer than one season when the proper conditions are available, but they cannot maintain viability indefinitely and will eventually deteriorate and die. The external factors that have the most influence on seed longevity are the relative humidity and temperature. He cites Harrington (1960) that the sum of the relative humidity, in percentage, plus the temperature in Fahrenheit should not exceed 100 for safe storage. An R.H. above 75% will cause seed moistures to exceed 15%. Copeland (1976) further states that seeds of most species may be stored for several years by careful control of temperature and relative humidity but that such storage conditions are too costly for most agriculture seed lots such as corn and, as the seed deteriorates, one can expect delayed emergence, slower rates of seedling growth and development, decreased germination rates, and a decreased resistance to stress.

Justice and Bass (1978) state that the purpose of storing seeds is to preserve planting stock from one season until the next and that there are advantages of carrying over seeds for two or more years to accommodate low crop years and an unknown, changing demand. Seeds are physiologically mature when they attain maximum dry weight and from that point on they gradually lose vigor and eventually die. This life process can be manipulated but not stopped. They cite research as far back as 1832 that showed seed vitality would be prolonged if stored under conditions that would protect from heat, moisture, and oxygen. They agree that seed moisture content during storage is the most influential factor affecting their longevity.

Normal seed respiration combines hexose with oxygen to give off carbon dioxide, water, and heat. This respiration can be reduced by keeping the seed dry and cool. Justice and Bass (1978) have found that storage for 3 to 5 years at ambient temperatures can be safely done in a sealed container after first drying the seeds to 5 - 8 percent moisture. Even longer storage can be expected if the seed moisture is reduced down 2 1/2 to 5 percent. The National Seed Storage Lab at Fort Collins, Colorado, stores most of their seed in sealed pint sized cans at a temperature of 4°C and an R.H. of 35%.

Barton (1961) reports that corn seeds with a moisture content above 15% suffer severe damage at all temperatures and have even greater damage with fluctuating temeratures.

Whitney (1980) has found that sensitive vegetable seeds can have a normally short storage lengthened to a guaranteed 3 years by packaging in a sealed aluminum/polyethylene laminate material and stored at 18°C, 25% R.H., but suggest that the procedure is not economically feasible for large quantities of common seeds.

Bass and Clark (1967) reported that corn seeds maintained a 90% germination rate after 7 years of storage when the seed was dried to 10% moisture, sealed in a moisture-proof container and stored at 4°C and ambient R.H. For maximum longevity, seeds should be dried to 3-7% moisture sealed in moisture-proof containers and stored at -10°C. He says that, overall, seed moisture is the most critical factor in seed storage. This statement agrees with all other published reports.

Treating corn seeds with a fungicide prior to storage does not reduce germination rates and, according to Das et al. (1975), this treatment would generally result in a higher germination rate than untreated seeds. Seeds used for this study were treated with a fungicide.

Justice and Bass (1978) state that several theories have been proposed on what causes a seed to deteriorate, none of which satisfactorily explain how seeds deteriorate. Even though the process of deterioration is not clearly understood, the methods for slowing it are well established.

Other articles and books have been written on general seed storage and all agree with previously discussed findings. No publication could be found on studies of corn seed stored in various packaging materials in seasonal ambient conditions of fluctuating temperatures and relative humidity.

MATERIALS AND METHODS

1. The following four packaging materials were studied:

   A. Four ply multi-wall stitched top and bottom paperbags. The three inner layers were unbleached kraft having a basis weight of 60 pounds and a thickness of 6 points. The outside layer was bleached kraft, having a basis weight of 60 pounds and a thickness of 7 points. Total surface area of the bag is 1,054 square inches. Seam to surface ratio was 1:29 (inch to inch^2). Surface area per seed was .013 in^2/seed, 80,000 seeds per bag.

   Experimental bags were made from donated commercial bags that were cut down to make small bags measuring 6.5 inches by 5.25 inches which provided a total surface area of 68.25 square inches. Seam to surface ratio was 1:65 (inch to inch^2). Surface area per seed was .114 in^2/seed, 600 seeds per bag.

   Both top and bottom were closed by stitching with cotton thread to duplicate the commercial bags. Side seams were glued.

   Each testing period, six of these packages were removed to provide 24 warm germination tests and 24 cold germination tests. All other packages provided 12 samples of warm and cold germination tests from 3 packages.

B. Four ply multi-walled paper bags with a .7 mil layer of low density polyethylene (LDPE) between layers 2 and 3. The three inner layers of paper were unbleached kraft having a basis weight of 60 pounds and were 6 points thick. The outside layer was 60 pounds, 7 points bleached kraft and the buried PE was 0.7 mils. Total bag surface area is 1,054 square inches. Seam to surface ratio was 1:29 (inch to $inch^2$). Surface area per seed was .013 in^2/seed.

Test bags were cut down from full size commercial bags and measured 6.5 inches by 5.25 inches with a total surface area of 68.25 square inches. Seam to surface area ratio was 1:65 (inch to $inch^2$). Surface area per seed is .114 in^2/seed, 600 seeds per bag. Both top and bottom were closed by stitching with cotton thread. The paper side seams were glued. The LDPE side seams were heat sealed.

C. Two mil low density polyethylene tubes. These were made into heat sealed bags measuring 5.5 inches by 4 inches (flat) for a total surface area of 44 square inches. Surface area per seed was .073 in^2/seed, 600 seeds per bag.

D. Steel Cans. 302 x 408, exterior tinplate, interior enamel with a machine applied double seamed end.

2. The test seed was hybrid corn, variety number 2443, lot number 10,978 with a germination test date of 10-01-81 at 98%. These seeds were supplied by Great Lakes Hybrids, Inc., Ovid, Michigan.

3. The storage container for all seeds stored under ambient conditions was made of wood framing and 1/4 inch hardware cloth. It measured 48 x 33 x 26 inches. Its purpose was to protect from rodents and other pests that might cause damage to the test packages and seeds. The storage container had six layers of storage that provided for complete air circulation on all external surfaces (see Figure 1) of the test package. Separation of layers was provided by a frame with 4 inch wooden legs and a bed of 1 inch mesh chicken fencing. Each layer held 24 test packages proportioned from all four types of packages. Sampling consisted of removing 6 paper bags, 3 paper/LDPE bags, 3 LDPE bags and 3 steel cans at 3 month intervals without disturbing the remaining samples.

4. Accelerated Storage. Accelerated storage testing was done in a high temperature (100°F), high humidity (85%) environment for the purpose of accelerating the seed's deterioration rate, which allows a shelf life determination in a shortened time period. This testing was conducted in a Michigan State University walk-in, controlled environmental room (Lab-Line Instrument Inc.).

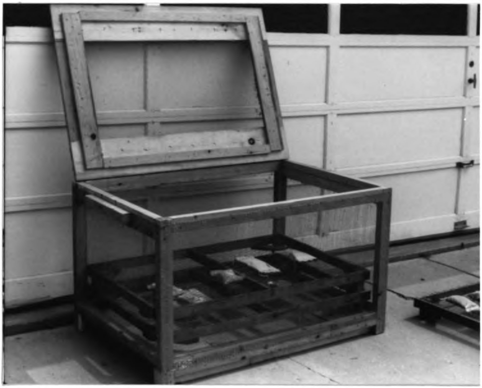

Fig. 1. Storage Container.

5. Germination Paper. Standard commercially available germination paper was used for the seed bed in accordance with "The Association of Official Seed Analysts Rules for Testing Seeds". Both warm and cold testing was conducted. All seed was placed on the moistened germination paper, 100 seeds per paper, in 2 groups of 50 for ease of counting and statistical analysis (see Figure 2). Cold test samples were stored at 10^{o}C for 7 days prior to testing. Both warm and cold test samples were placed in 25^{o}C germination chambers at the Michigan Crop Improvement Association Laboratory. After seven days, each seed was studied for abnormal or normal germination and recorded as percent germinated. Details of seed germination testing may be found in above cited rules for testing.

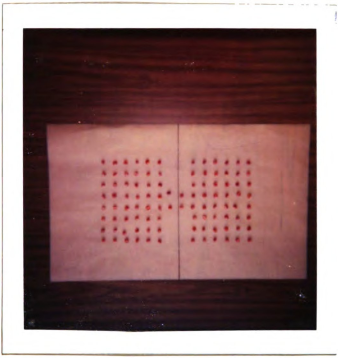

Fig. 2. Seed Placement on Germination Paper.

6. Scales. All weight measurements were performed with a Mettler P1000 standard platform scale capable of measuring to .01 grams, and a Mettler AE160 capable of measuring to .0001 grams.

7. Headspace Gases. Headspace gases of oxygen, carbon dioxide, and nitrogen were measured by a Carle GC8700 gas chromatograph with a Porapak Q column. Gas peaks were recorded on a Heath-Zenith strip chart recorder model SR204.

8. Initial Moisture Determination. Initial seed moisture was measured in accordance with AOAC (Methods of Analysis of the Association of

Official Analytical Chemists). Sample seed was ground up using a number 20 sieve, weighed on a Mettler balance, and placed in a vacuum oven. The vacuum system was a Michigan State University, Welch Duo Seal Vacuum pump model 1400, and a National Appliance Company Model 583 vacuum oven. Drying conditions were 100°C with a pressure equivalent of approximately 25 mmHg for 5 hours. Controlled cooling was in a standard laboratory desiccator.

RESULTS

Experiments were carried out according to previously described procedures. Results are shown in Figures 3-7 and in Tables 1-22. Figure 3 shows that headspace CO_2 changed in the steel cans, all others were unchanged.

Figure 4 shows that headspace oxygen decreased in the steel cans with a small decrease in the plastic bag. All others were unchanged.

Figure 5 shows the seasonal affect changing relative humidity has on the test seed.

Figure 6 shows the packaged seed germination deterioration over time (warm test).

Figure 7 shows the packaged seed germination deterioration over time (cold test).

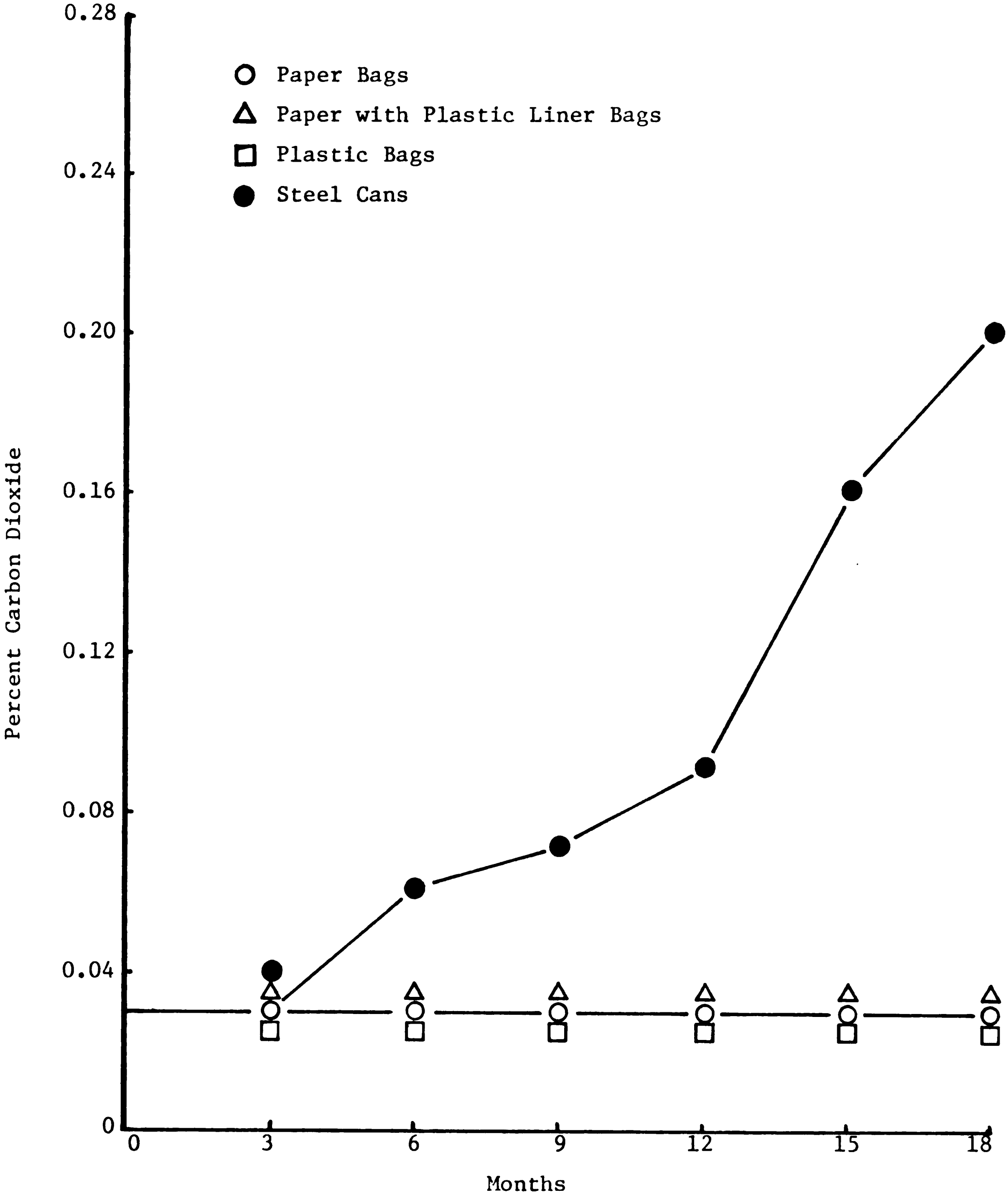

Fig. 3. Headspace Carbon Dioxide.

TABLE 1. HEADSPACE CARBON DIOXIDE PERCENT.

Time (Months)	Paper Bags	Paper/Plastic Lined Bags	Plastic Bags	Steel Cans
3	.03	.03	.03	.03
6	.03	.03	.03	.06
9	.03	.03	.03	.07
12	.03	.03	.03	.09
15	.03	.03	.03	.16
18	.03	.03	.03	.20

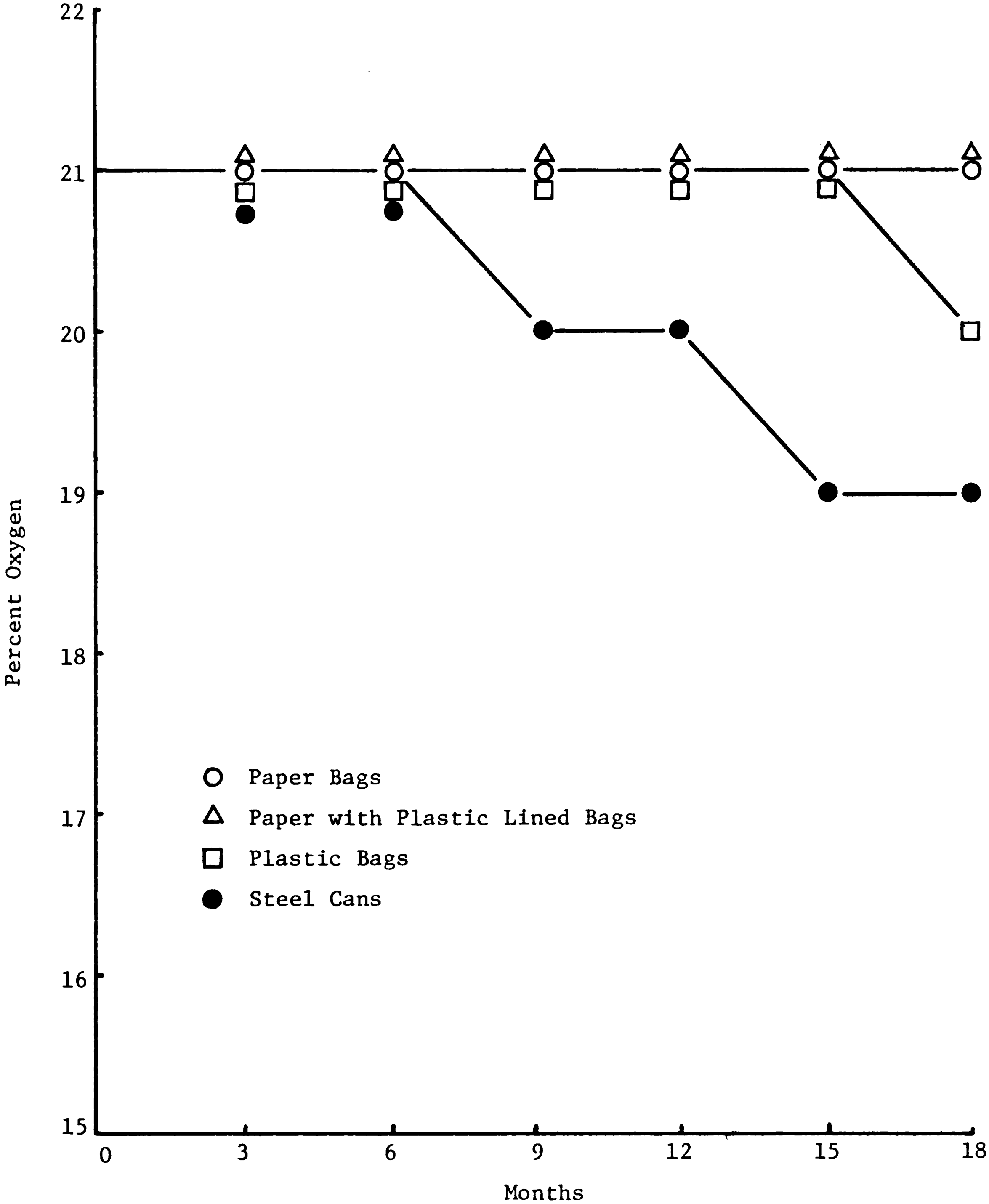

Fig. 4. Headspace Oxygen.

TABLE 2. HEADSPACE OXYGEN PERCENT

Time (Months)	Paper Bags	Paper/Plastic Lined Bags	Plastic Bags	Steel Cans
3	21	21	21	21
6	21	21	21	21
9	21	21	21	20
12	21	21	21	20
15	21	21	21	19
18	21	21	20	19

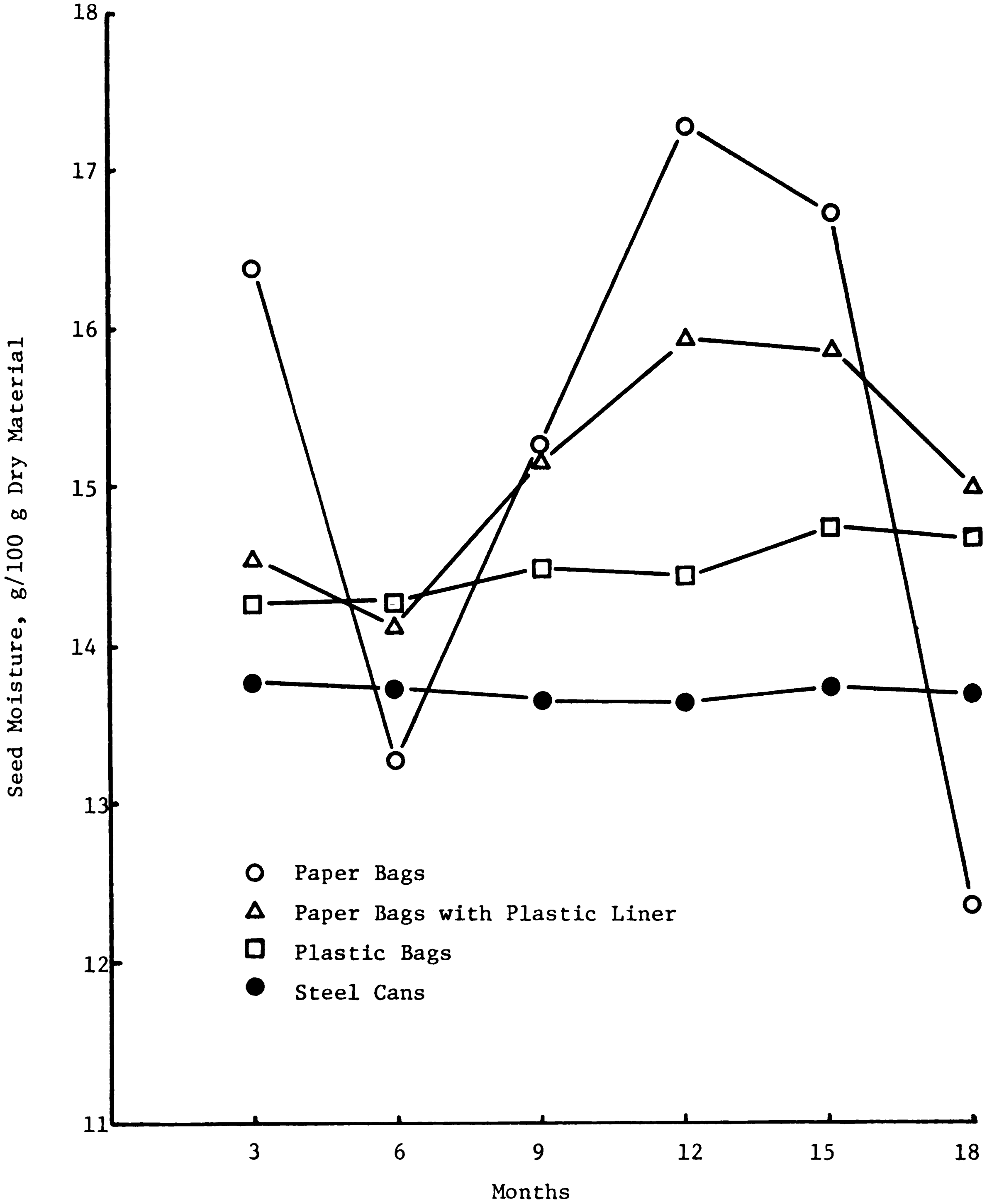

Fig. 5. Seed Moisture, Grams H_2O/100 Grams Dry Material.

TABLE 3. SEED MOISTURE, GRAMS H_2O/100 GRAMS DRY MATERIAL/STANDARD DEVIATION.

Time (Months)	Paper Bags	Paper/Plastic Lined Bags	Plastic Bags	Steel Cans
3	16.39/.3	14.53/.03	14.22/.03	13.74/.05
6	13.26/.1	14.08/.13	14.23/.03	13.69/.01
9	15.27/.62	15.16/.03	14.48/.03	13.59/.02
12	17.24/.64	15.90/.04	14.38/.26	13.59/.09
15	16.69/.28	15.82/.67	14.71/.07	13.69/.07
18	12.34/.13	14.99/.03	14.63/.03	13.62/.17

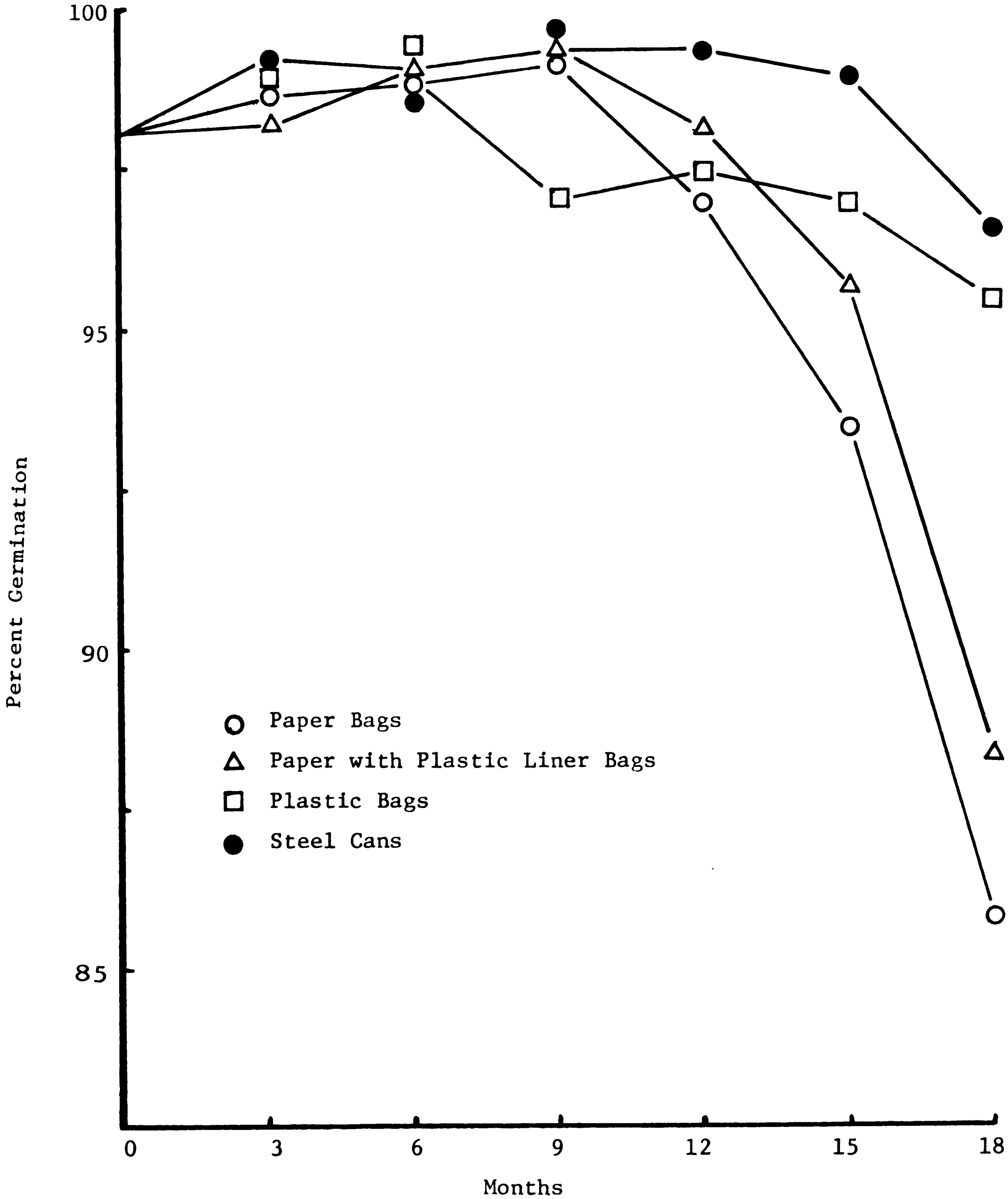

Fig. 6. Seed Germination Rate (Warm Test)

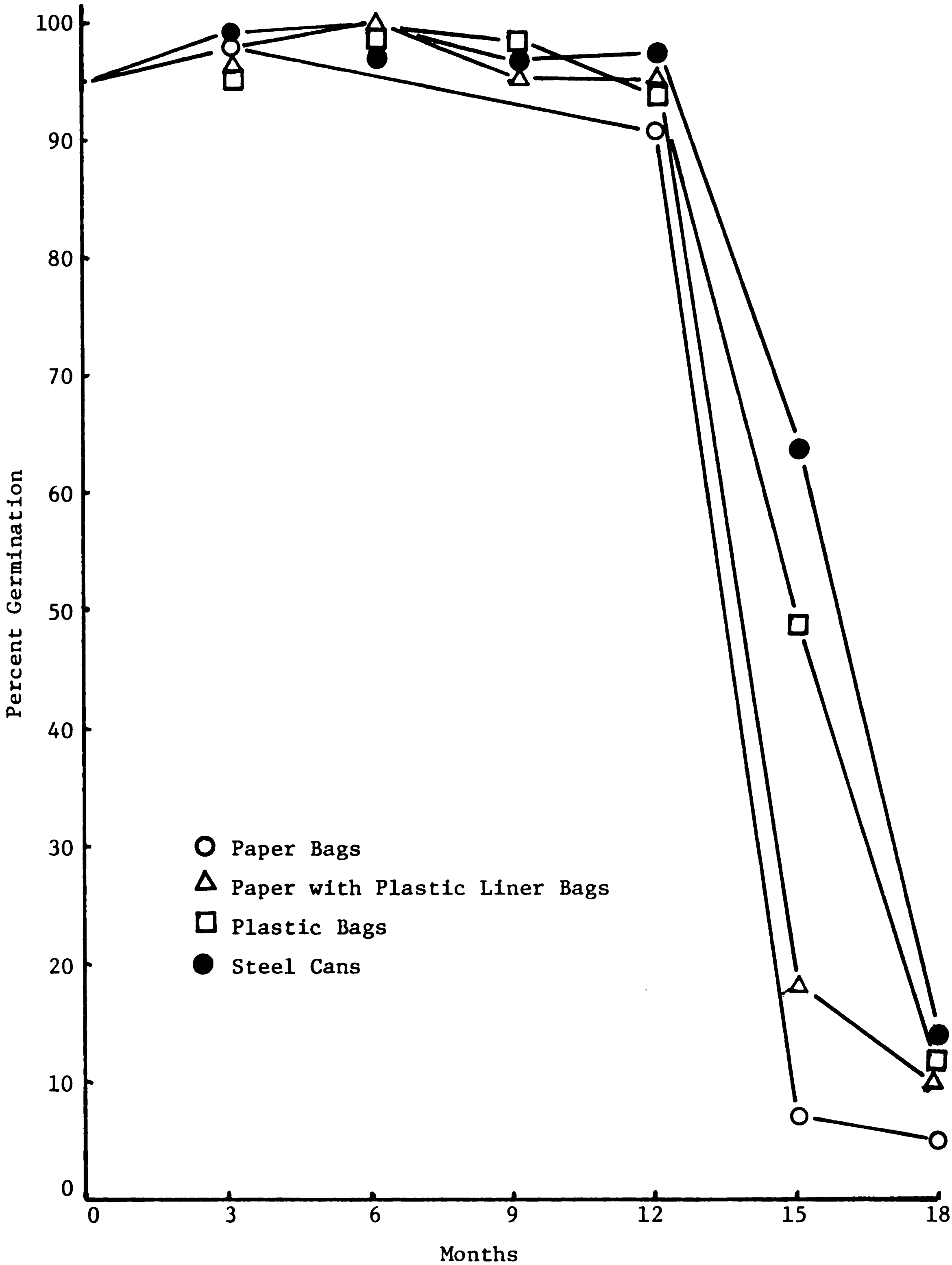

Fig. 7. Seed Germination Rate (Cold Test).

TABLE 4. GERMINATION RATE (%) WITH STANDARD DEVIATION (WARM TEST).

Time (Months)	Paper Bags	Paper With Plastic Liner	Plastic Bags	Steel Cans
3	98.50 ± 1.59	98.08 ± 1.24	98.58 ± 1.16	99.00 ± 0.95
6	98.75 ± 1.85	98.83 ± 1.34	98.83 ± 1.99	99.00 ± 1.35
9	99.17 ± 1.31	99.50 ± 0.90	97.00 ± 2.49	99.50 ± 0.90
12	97.00 ± 2.89	97.83 ± 2.62	97.50 ± 2.84	99.33 ± 0.93
15	93.42 ± 3.36	95.67 ± 2.33	97.00 ± 2.76	99.00 ± 1.60
18	85.83 ± 6.46	88.33 ± 2.93	94.50 ± 3.09	96.50 ± 2.71

TABLE 5. GERMINATION RATE (%) WITH STANDARD DEVIATION (COLD TEST).

Time (Months)	Paper Bags	Paper With Plastic Liner	Plastic Bags	Steel Cans
3	98.29 ± 2.01	98.25 ± 1.29	99.25 ± 0.75	99.08 ± 0.90
6	Destroyed	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
9	Destroyed	95.33 ± 4.77	98.50 ± 1.51	96.83 ± 3.46
12	91.33 ± 5.52	95.17 ± 2.62	93.83 ± 4.71	97.83 ± 1.99
15	6.46 ± 4.13	17.17 ± 8.38	48.17 ± 19.00	63.67 ± 11.05
18	4.50 ± 2.72	9.00 ± 4.47	9.17 ± 2.48	13.33 ± 4.38

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DISCUSSION

Justice and Bass (1978) and others have stated that storage temperature and seed moisture content are the most important factors affecting seed longevity, with seed moisture content usually more influential than temperatures. Copeland (1976) cited studies of grass seed packaged in various materials that showed the better moisture barrier materials maintained a higher seed germination rate.

The results of this study support published data of general seed storage research. This study does concentrate on a specific species of hybrid corn seed and a specific hybrid out of many hybrid corn seeds. What was found to be true for this particular seed may not apply specifically to other hybrid corn seeds found throughout the world and indeed to other hybrids from the same grower where these seeds were obtained. Research by previously cited authors suggests that all corn seeds would react to packaging in a similar manner. Justice and Bass (1978) point out that many other factors, such as mechanical damage during harvest and handling, seed maturity at harvest, and other problems do influence seed longevity. This study is directed to the problems of the seed companies, the distributors, and the farmers that have uncontrolled storage conditions and are interested in having an acceptable germination rate at the time of planting.

Once the research seeds were packaged and put into storage only the factors of seed temperature and seed moisture content influenced natural aging of the seed. Harrington (1972) states that each 5°C increase in seed storage temperature will reduce the seed life by about half. During this study, which extended over two Michigan winters, the ambient storage temperature varied from a low of -10°C to +35°C with many fluctuations between extremes. According to Harrington (1972), this temperature change did harm the seed. This study recognizes the importance of temperature control but is restricted to relative humidity influence and how the packaging material might extend the shelf life of a specific corn seed.

Headspace gases were monitored throughout the study period and were found to have measurable changes only where they were fully contained by the package. Only the steel can had a significant change in carbon dioxide and oxygen. All other packaging materials have a gas permeation rate that allowed headspace gases to be in equilibrium with the atmosphere. Figures 3 and 4, in the Results Section, shows the steel can's ability to retain gases. Figure 5 in the Results Section deals with measurement of moisture in the seed. Moisture changes are influenced by the packaging material's water vapor transmission rate. Harrington (1960) states, as a "rule of thumb", that the life of a seed is halved for each 5°C increase in seed storage temperature and for each 1% increase in seed moisture content. Combining Figures 5, 6, and 7 in the Results Section shows some correlation and generally supports the work of Harrington (1960) and others in seed storage.

A warm and a cold seed germination test was conducted in accordance with "The Association of Official Seed Analysts Rules for Testing Seeds".

The warm germination test is a measure of seed viability or the ability to produce a normal seedling. This test is accomplished by placing a quantity of seed between moistened germination paper that is then rolled up in a protective layer of wax paper and placed in a 25°C germination chamber for seven days. After seven days the seed is observed for normal and abnormal seedlings. The Michigan Seed Foundation requires a minimum of 90% normal seed germination for certification. Only warm germination results are recorded on the seed data card.

The cold germination test is conducted to measure seedling vigor. This test is not required by the Michigan Seed Foundation. This test is started the same as for warm testing except 1 cm of moist soil is placed over the seed before rolling the paper up. The rolled up seed is then placed in a cold chamber (10°C) for seven days followed by the warm (25°C) germination chamber for seven days. Evaluation is the same as in the warm test and measures a seed's ability to overcome stress before regular germination. The Michigan Seed Foundation states that a good seed should have a cold test of 75% germination or better, but is a measure of seed vigor and is not recorded on the seed data card for certification.

Statistical analysis of seed germination rates does not identify any significant difference of the packaging materials' protective ability until the 15th and 18th month of storage. At the 18th month of storage, seeds in the steel can and the plastic bag tested well above the 90% germination minimum for certification and could have been sold as certified seed. The paper and paper/plastic bags were well below minimum certification and could not have been sold as certified seed.

CONCLUSION

Packaging material does have a significant influence on stored corn seed germination rates. The steel can, or containers of equally high impermeability properties, provides the best protection of stored seed but they are not economically practicable for large quantities of agricultural seeds.

Multiwall paper bags serve the function of containing and handling bushel size seed packages, but do not provide any protection from climatic conditions. The inclusion of a thin layer of plastic in the multiwall paper bags does increase the protection to the seed slightly, but stitch closing and lack of heat sealing of the top and bottom reduces the potential protection qualities of the plastic.

Low density polyethylene bags provide significant protection from moisture and do a good job of maintaining germination rates and thus extending the shelf life of corn seeds.

Seed stored in the steel cans and the sealed plastic bags passed the warm germination test for certified seed after 18 months of storage. Paper based packages could not have been certified after 18 months of storage.

RECOMMENDATIONS

The research conducted for this study suggests that if commercial corn seed companies switched from the traditional multiwall paper bags to a 4 mil low density polyethylene bag they would increase the shelf life of their product. Current cost of a 4 mil LDPE bag measuring 16" x 28" is $0.1318, while a comparable size 4-ply multiwall bag costs $0.23. Therefore, the cost of switching to plastic packaging material should be a plus factor.

Moisture protection from a permeation point will be twice as good (4 mil vs. 2 mil) as the material studied in the research. Also, the seed to packaging material area will be reduced from .073 in^2 per seed in the test bag to .013 in^2 per seed in the commercial size bag, which significantly reduces (82%) the amount of permeating moisture per seed.

Graphics should not be a problem on LDPE bags. If necessary, a layer of quality printing paper could easily be laminated to the plastic with little increase in cost. Switching from paper bags to polyethylene bags will result in reducing packaging costs and extending the shelf life of corn seeds and should be considered by commercial seed companies.

APPENDIX A

INITIAL SEED MOISTURE DATA

APPENDIX A

INITIAL SEED MOISTURE DATA

TABLE 6. INITIAL SEED MOISTURE DATA.

Date	Sample	Initial Weight	Final Weight	Percent H_2O
1-4-82	1	2.0200 g	1.7668 g	12.5347
	2	2.0000 g	1.7490 g	12.5500
	3	2.0021 g	1.7518 g	12.5019

Average Moisture = 12.5287%

g H_2O/100 g dry matter = 14.3235 g

Standard Deviation* = 0.02

*See Appendix F for moisture formula.

APPENDIX B

HEADSPACE GAS DATA

APPENDIX B

HEADSPACE GAS DATA

TABLE 7. HEADSPACE GAS DATA - PAPER BAGS.

Date	Package Code	% CO_2	Batch Average	% O_2	Batch Average
3-21-82	P1R	.03		21.0	
	P4R	.03		21.0	
	P5R	.03		21.0	
	P6R	.03		21.0	
	P7R	.03		21.0	
	P8R	.03	.03	21.0	21.0
7-01-82	P2R	.03		21.0	
	P3R	.03		21.0	
	P9R	.03		21.0	
	P10R	.03		21.0	
	P11R	.03		21.0	
	P12R	.03	.03	21.0	21.0
9-22-82	P13R	.03		21.0	
	P14R	.03		21.0	
	P15R	.03		21.0	
	P16R	.03		21.0	
	P23R	.03		21.0	
	P24R	.03	.03	21.0	21.0
12-15-82	P17R	.03		21.0	
	P18R	.03		21.0	
	P19R	.03		21.0	
	P20R	.03		21.0	
	P21R	.03		21.0	
	P22R	.03	.03	21.0	21.0
3-20-83	P27R	.03		21.0	
	P28R	.03		21.0	
	P29R	.03		21.0	
	P30R	.03		21.0	
	P31R	.03		21.0	
	P32R	.03	.03	21.0	21.0

TABLE 7 (Continued)

Date	Package Code	% CO_2	Batch Average	% O_2	Batch Average
6-15-83	P26R	.03		21.0	
	P36R	.03		21.0	
	P37R	.03		21.0	
	P38R	.03		21.0	
	P39R	.03		21.0	
	P40R	.03	.03	21.0	21.0

TABLE 8. HEADSPACE GAS DATA - PAPER WITH PLASTIC LINER BAGS.

Date	Package Code	% CO_2	Batch Average	% O_2	Batch Average
3-21-82	PP2R	.03		21.0	
	PP3R	.03		21.0	
	PP1R	.03	.03	21.0	21.0
7-01-82	PP4R	.03		21.0	
	PP5R	.03		21.0	
	PP9R	.03	.03	21.0	21.0
9-22-82	PP6R	.03		21.0	
	PP7R	.03		21.0	
	PP10R	.03	.03	21.0	21.0
12-15-82	PP8R	.03		21.0	
	PP12R	.03		21.0	
	PP15R	.03	.03	21.0	21.0
3-20-83	PP11R	.03		21.0	
	PP13R	.03		21.0	
	PP14R	.03	.03	21.0	21.0
6-15-83	PP17R	.03		21.0	
	PP18R	.03		21.0	
	PP19R	.03	.03	21.0	21.0

TABLE 9. HEADSPACE GAS DATA - POLYETHYLENE BAGS.

Date	Package Code	% CO_2	Batch Average	% O_2	Batch Average
3-21-82	PE4R	.03		21.0	
	PE5R	.03		21.0	
	PE6R	.03	.03	21.0	21.0
7-01-82	PE1R	.03		20.8	
	PE2R	.03		20.8	
	PE3R	.03	.03	20.8	20.8
					S.D. = 0.0
9-22-82	PE7R	.03		20.8	
	PE8R	.03		20.8	
	PE9R	.03	.03	21.0	20.9
					S.D. = 0.10
12-15-82	PE15R	.03		21.0	
	PE16R	.03		21.0	
	PE17R	.03	.03	21.0	21.0
3-20-83	PE10R	.03		21.0	
	PE11R	.03		21.0	
	PE12R	.03	.03	21.0	21.0
6-15-83	PE13R	.03		20.0	
	PE14R	.03		20.4	
	PE23R	.03	.03	20.4	20.3
					S.D. = 0.20

TABLE 10. HEADSPACE GAS DATA - STEEL CANS.

Date	Package Code	% CO_2	Batch Average	% O_2	Batch Average
3-21-82	SC2R	.03		21.0	
	SC3R	.03		21.0	
	SC4R	.03	.03	21.0	21.0
7-01-82	SC1R	.06		21.0	
	SC5R	.06		21.0	
	SC6R	.06	.06	21.0	21.0
9-22-82	SC8R	.08		20.0	
	SC10R	.08		20.0	
	SC11R	.08	.08	20.0	20.0
12-15-82	SC7R	.03		20.0	
	SC9R	.04		20.0	
	SC12R	.04	.04	20.0	20.0
			S.D.=.0054		
3-20-83	SC13R	.18		19.5	
	SC14R	.16		19.0	
	SC16R	.17	.17	19.7	19.4
			S.D.=.008		S.D. = .29
6-15-83	SC15R	.19		19.6	
	SC19R	.19		19.3	
	SC20R	.21	.20	19.5	19.5
			S.D.=.01		S.D. = .12

APPENDIX C

SEED MOISTURE DATA

APPENDIX C

SEED MOISTURE DATA

TABLE 11. SEED MOISTURE DATA - PAPER BAGS.

Date	Package Code	Initial Weight (g)	Final Weight (g)	g H_2O/100 g Dry Matter	Batch Average	S.D.
3-21-82	P1R	201.2	204.3	16.09		
	P4R	204.3	208.4	16.62		
	P5R	218.9	222.8	16.36		
	P6R	188.4	191.9	16.45		
	P7R	203.4	207.8	16.80		
	P8R	200.8	203.8	16.03	16.39	0.30
7-01-82	P2R	199.5	197.6	13.24		
	P3R	199.3	197.6	13.35		
	P9R	201.8	199.9	13.25		
	P10R	194.1	192.4	13.32		
	P11R	201.5	199.3	13.08		
	P12R	200.6	198.8	13.30	13.26	0.10
9-22-82	P13R	192.9	195.1	15.63		
	P14R	204.2	206.8	15.78		
	P15R	195.9	198.5	15.84		
	P16R	199.2	200.9	15.30		
	P23R	196.6	197.3	14.73		
	P24R	200.5	200.5	14.32	15.27	0.62
12-15-82	P17R	212.4	218.3	17.50		
	P18R	204.4	210.2	17.57		
	P19R	199.3	204.6	17.37		
	P20R	208.2	213.7	17.35		
	P21R	204.0	210.0	17.69		
	P22R	197.3	200.1	15.95	17.24	0.64
3-20-83	P27R	203.6	208.0	16.80		
	P28R	192.5	196.2	16.52		
	P29R	204.4	208.4	16.56		
	P30R	204.5	209.3	17.01		
	P31R	203.0	206.5	16.30		
	P32R	203.3	208.0	16.97	16.69	0.28

TABLE 11 (Continued)

Date	Package Code	Initial Weight (g)	Final Weight (g)	g H_2O/100 g Dry Matter	Batch Average	S.D.
6-15-83	P26R	196.6	193.3	12.41		
	P36R	194.6	191.3	12.39		
	P37R	200.8	197.3	12.33		
	P38R	202.4	199.2	12.52		
	P39R	196.0	192.5	12.28		
	P40R	207.4	203.4	12.12	12.34	0.13

TABLE 12. SEED MOISTURE DATA - PAPER/PLASTIC LINED BAGS.

Date	Package Code	Initial Weight (g)	Final Weight (g)	g H_2O/100 g Dry Matter	Batch Average	S.D.
3-21-82	PP2R	200.6	201.0	14.55		
	PP3R	200.7	201.1	14.55		
	PP1R	201.8	202.1	14.49	14.53	0.03
7-01-82	PP4R	201.4	201.1	14.15		
	PP5R	199.8	199.5	14.15		
	PP9R	200.5	199.8	13.93	14.08	0.13
9-22-82	PP6R	200.3	201.8	15.18		
	PP7R	199.9	201.4	15.18		
	PP10R	200.4	201.8	15.12	15.16	0.03
12-15-82	PP8R	200.1	202.9	15.92		
	PP12R	200.3	203.1	15.92		
	PP15R	200.8	203.5	15.86	15.90	0.04
3-20-83	PP11R	200.5	204.0	16.32		
	PP13R	201.5	204.6	16.08		
	PP14R	200.2	201.5	15.07	15.82	0.67
6-15-83	PP17R	200.6	201.8	15.01		
	PP18R	200.0	201.2	15.01		
	PP19R	200.8	201.9	14.95	14.99	0.03

TABLE 13. SEED MOISTURE DATA - POLYETHYLENE BAGS.

Date	Package Code	Initial Weight (g)	Final Weight (g)	g H_2O/100 g Dry Matter	Batch Average	S.D.
3-21-82	PE4R	200.0	199.9	14.27		
	PE5R	200.2	200.0	14.21		
	PE6R	200.0	199.8	14.21	14.22	0.03
7-01-82	PE1R	200.4	200.2	14.21		
	PE2R	200.2	200.1	14.27		
	PE3R	200.5	200.3	14.21	14.23	0.03
9-12-82	PE7R	200.3	200.6	14.50		
	PE8R	200.2	200.5	14.50		
	PE9R	200.3	200.5	14.44	14.48	0.03
12-15-82	PE15R	200.3	200.8	14.61		
	PE16R	200.3	200.5	14.44		
	PE17R	200.0	199.6	14.10	14.38	0.26
3-20-83	PE10R	200.3	201.1	14.78		
	PE11R	200.5	201.1	14.67		
	PE12R	200.1	200.7	14.67	14.71	0.07
6-15-83	PE13R	200.2	200.8	14.67		
	PE14R	200.2	200.7	14.61		
	PE23R	199.9	200.4	14.61	14.63	0.03

TABLE 14. SEED MOISTURE DATA - STEEL CANS.

Date	Package Code	Initial Weight (g)	Final Weight (g)	g H_2O/100 g Dry Matter	Batch Average	S.D.
3-21-82	SC2R	254.2	252.9	13.74		
	SC3R	251.5	250.1	13.69		
	SC4R	259.5	258.3	13.80	13.74	0.05
7-01-82	SC1R	247.3	245.9	13.68		
	SC5R	247.4	246.0	13.68		
	SC6R	256.1	254.7	13.70	13.69	0.01
9-12-82	SC8R	249.0	247.4	13.59		
	SC10R	241.4	239.8	13.57		
	SC11R	254.1	252.5	13.61	13.59	0.02
12-15-82	SC7R	245.2	243.5	13.53		
	SC9R	250.3	248.6	13.55		
	SC12R	257.8	256.4	13.70	13.59	0.09
3-20-83	SC13R	256.4	255.0	13.70		
	SC14R	256.5	254.9	13.61		
	SC16R	256.0	254.7	13.74	13.69	0.07
6-15-83	SC15R	250.6	249.0	13.59		
	SC19R	253.7	251.8	13.47		
	SC20R	243.1	242.0	13.81	13.62	0.17

APPENDIX D

SEED GERMINATION DATA (WARM TEST)

APPENDIX D

SEED GERMINATION DATA (WARM TEST)

TABLE 15. SEED GERMINATION DATA - WARM TEST - PAPER BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	P1R	95 - 99 - 96 - 100		
	P4R	98 - 96 - 99 - 99		
	P5R	99 - 96 - 100 - 100		
	P6R	98 - 98 - 99 - 96		
	P7R	98 - 100 - 100 - 100		
	P8R	99 - 99 - 100 - 100	98.5	1.59
7-01-82	P2R	100 - 100 - 98 - 94		
	P3R	100 - 100 - 96 - 100		
	P9R	98 - 96 - 96 - 100		
	P10R	100 - 100 - 96 - 100		
	P11R	100 - 100 - 100 - 100		
	P12R	100 - 98 - 98 - 100	98.6	1.85
9-22-82	P13R	98 - 100 - 100 - 98		
	P14R	100 - 98 - 100 - 100		
	P15R	100 - 98 - 100 - 98		
	P16R	100 - 100 - 96 - 100		
	P23R	96 - 100 - 100 - 98		
	P24R	100 - 100 - 100 - 100	99.2	1.31
12-15-82	P17R	98 - 98 - 92 - 96		
	P18R	98 - 100 - 94 - 94		
	P19R	100 - 100 - 96 - 96		
	P20R	100 - 98 - 98 - 98		
	P21R	98 - 100 - 96 - 100		
	P22R	92 - 100 - 90 - 96	97.0	2.89
3-20-83	P27R	100 - 90 - 90 - 92		
	P28R	98 - 98 - 98 - 88		
	P29R	92 - 90 - 94 - 96		
	P30R	90 - 90 - 90 - 96		
	P31R	94 - 94 - 92 - 92		
	P32R	92 - 92 - 96 - 98	93.4	3.36

TABLE 15 (Continued)

Date	Package Code	Germination %	Batch Average	Standard Deviation
6-15-83	P26R	86 - 94 - 94 - 96		
	P36R	84 - 80 - 76 - 74		
	P37R	88 - 80 - 92 - 76		
	P38R	90 - 84 - 92 - 76		
	P39R	92 - 90 - 92 - 88		
	P40R	86 - 84 - 82 - 84	85.8	6.46

TABLE 16. SEED GERMINATION DATA - WARM TEST - PAPER/PLASTIC LINED BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	PP2R	97 - 96 - 98 - 97		
	PP3R	97 - 100 - 100 - 98		
	PP1R	98 - 99 - 99 - 98	98.1	1.24
7-01-82	PP4R	100 - 98 - 98 - 100		
	PP5R	96 - 100 - 98 - 98		
	PP9R	100 - 100 - 98 - 100	98.8	1.34
9-22-82	PP6R	100 - 98 - 100 - 100		
	PP7R	100 - 98 - 100 - 98		
	PP10R	100 - 100 - 100 - 100	99.5	0.90
12-15-82	PP8R	100 - 100 - 98 - 100		
	PP12R	98 - 94 - 94 - 94		
	PP15R	96 - 100 - 100 - 100	97.8	2.62
3-20-83	PP11R	94 - 94 - 96 - 94		
	PP13R	94 - 94 - 98 - 98		
	PP14R	100 - 94 - 98 - 94	95.7	2.23
6-15-83	PP17R	96 - 86 - 90 - 88		
	PP18R	86 - 90 - 88 - 86		
	PP19R	86 - 86 - 88 - 90	88.3	2.93

TABLE 17. SEED GERMINATION DATA - WARM TEST - POLYETHYLENE BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	PE4R	98 - 100 - 96 - 100		
	PE5R	98 - 98 - 98 - 99		
	PE6R	98 - 99 - 99 - 100	98.6	1.16
7-01-82	PE1R	100 - 100 - 98 - 98		
	PE2R	96 - 100 - 100 - 100		
	PE3R	100 - 100 - 94 - 100	98.8	1.99
9-22-82	PE7R	100 - 100 - 94 - 100		
	PE8R	96 - 98 - 98 - 96		
	PE9R	92 - 96 - 98 - 96	97.0	2.49
12-15-82	PE15R	92 - 100 - 98 - 98		
	PE16R	92 - 98 - 96 - 98		
	PE17R	100 - 100 - 98 - 100	97.5	2.84
3-20-83	PE10R	94 - 100 - 98 - 98		
	PE11R	100 - 92 - 100 - 96		
	PE12R	96 - 94 - 100 - 96	97.0	2.76
6-15-83	PE13R	96 - 98 - 94 - 92		
	PE14R	88 - 98 - 98 - 94		
	PE23R	92 - 92 - 96 - 96	94.5	3.09

TABLE 18. SEED GERMINATION DATA - WARM TEST - STEEL CANS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	SC2R	98 - 99 - 97 - 99		
	SC3R	99 - 100 - 99 - 100		
	SC4R	100 - 100 - 99 - 98	99.0	0.95
7-01-82	SC1R	100 - 100 - 100 - 100		
	SC5R	96 - 100 - 98 - 100		
	SC6R	98 - 98 - 98 - 100	99.0	1.35
9-22-82	SC8R	100 - 100 - 98 - 98		
	SC10R	100 - 100 - 100 - 98		
	SC11R	100 - 100 - 100 - 100	99.5	0.90
12-15-82	SC7R	100 - 100 - 98 - 100		
	SC9R	98 - 100 - 98 - 100		
	SC12R	98 - 100 - 100 - 100	99.3	0.98
3-20-83	SC13R	100 - 100 - 100 - 100		
	SC14R	100 - 96 - 98 - 100		
	SC16R	96 - 100 - 98 - 100	99.0	1.60
6-15-83	SC15R	92 - 96 - 100 - 98		
	SC19R	92 - 98 - 98 - 96		
	SC20R	100 - 98 - 94 - 96	96.5	2.71

APPENDIX E

SEED GERMINATION DATA (COLD TEST)

APPENDIX E

SEED GERMINATION DATE (COLD TEST)

TABLE 19. SEED GERMINATION DATA - COLD TEST - PAPER BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	P1R	98 - 96 - 98 - 95		
	P4R	96 - 96 - 95 - 94		
	P5R	97 - 100 - 97 - 99		
	P6R	100 - 100 - 99 - 100		
	P7R	99 - 100 - 100 - 100		
	P8R	100 - 100 - 100 - 100	98.3	2.01
7-01-82	P2R			
	P3R			
	P9R	THIS BATCH CONTAMINATED		
	P10R	NO GERMINATION		
	P11R			
	P12R			
9-22-82	P13R			
	P14R			
	P15R	THIS BATCH CONTAMINATED		
	P16R	NO GERMINATION		
	P23R			
	P24R			
12-15-82	P17R	90 - 88 - 80 - 84		
	P18R	96 - 98 - 88 - 92		
	P19R	96 - 96 - 92 - 90		
	P20R	86 - 88 - 80 - 88		
	P21R	86 - 96 - 96 - 96		
	P22R	96 - 96 - 96 - 98	91.3	5.52
3-20-83	P27R	8 - 6 - 4 - 4		
	P28R	6 - 4 - 4 - 0		
	P29R	6 - 0 - 8 - 12		
	P30R	16 - 14 - 12 - 12		
	P31R	8 - 4 - 4 - 6		
	P32R	4 - 4 - 6 - 4	6.5	4.13

TABLE 19 (Continued)

Date	Package Code	Germination %	Batch Average	Standard Deviation
6-15-83	P26R	8 - 4 - 6 - 6		
	P36R	2 - 2 - 4 - 6		
	P37R	0 - 6 - 4 - 6		
	P38R	4 - 6 - 8 - 8		
	P39R	2 - 8 - 2 - 2		
	P40R	0 - 6 - 0 - 8	4.5	2.72

TABLE 20. SEED GERMINATION DATA - COLD TEST - PAPER/PLASTIC LINED BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	PP2R	99 - 99 - 98 - 100		
	PP3R	99 - 98 - 97 - 96		
	PP1R	99 - 99 - 99 - 96	98.3	1.29
7-01-82	PP4R	100 - 100 - 100 - 100		
	PP5R	DESTROYED		
	PP9R	100 - 100 - 100 - 100	100.0	0.00
9-22-82	PP6R	82 - 96 - 100 - 96		
	PP7R	96 - 98 - 96 - 100		
	PP10R	96 - 92 - 94 - 98	95.3	4.77
12-15-82	PP8R	94 - 96 - 96 - 98		
	PP12R	100 - 96 - 92 - 96		
	PP15R	96 - 94 - 90 - 94	95.2	2.62
3-20-83	PP11R	10 - 6 - 26 - 20		
	PP13R	10 - 6 - 30 - 26		
	PP14R	16 - 26 - 14 - 16	17.2	8.38
6-15-83	PP17R	6 - 10 - 8 - 10		
	PP18R	2 - 4 - 10 - 8		
	PP19R	10 - 8 - 12 - 20	9.0	4.47

TABLE 21. SEED GERMINATION DATA - COLD TEST - POLYETHYLENE BAGS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	PE4R	100 - 98 - 99 - 98		
	PE5R	100 - 100 - 100 - 99		
	PE6R	99 - 99 - 99 - 100	99.3	0.75
7-01-82	PE1R	100 - 100 - 100 - 100		
	PE2R	100 - 100 - 100 - 100		
	PE3R	100 - 100 - 100 - 100	100.0	0.00
9-22-82	PE7R	98 - 98 - 100 - 98		
	PE8R	100 - 100 - 96 - 100		
	PE9R	98 - 96 - 98 - 100	98.5	1.51
12-15-82	PE15R	96 - 98 - 92 - 92		
	PE16R	96 - 96 - 88 - 98		
	PE17R	82 - 96 - 96 - 96	93.8	4.71
3-20-83	PE10R	18 - 26 - 56 - 28		
	PE11R	60 - 62 - 64 - 24		
	PE12R	50 - 52 - 64 - 74	48.2	19.0
6-15-83	PE13R	6 - 12 - 10 - 10		
	PE14R	8 - 8 - 4 - 10		
	PE23R	12 - 10 - 8 - 12	9.2	2.48

TABLE 22. SEED GERMINATION DATA - COLD TEST - STEEL CANS.

Date	Package Code	Germination %	Batch Average	Standard Deviation
3-21-82	SC2R	99 - 98 - 100 - 100		
	SC3R	100 - 100 - 98 - 100		
	SC4R	98 - 99 - 99 - 98	99.1	0.90
7-01-82	SC1R	100 - 100 - 100 - 100		
	SC5R	100 - 100 - 100 - 100		
	SC6R	100 - 100 - 100 - 100	100.0	0.00
9-22-82	SC8R	100 - 96 - 100 - 88		
	SC10R	98 - 100 - 98 - 100		
	SC11R	96 - 96 - 94 - 96	96.8	3.46
12-15-82	SC7R	96 - 100 - 100 - 100		
	SC9R	100 - 98 - 98 - 96		
	SC12R	94 - 98 - 96 - 98	97.8	1.99
3-20-83	SC13R	60 - 66 - 72 - 70		
	SC14R	70 - 60 - 56 - 80		
	SC16R	50 - 52 - 80 - 48	63.7	11.05
6-15-83	SC15R	12 - 14 - 14 - 20		
	SC19R	8 - 6 - 14 - 12		
	SC20R	14 - 22 - 12 - 12	13.3	4.38

APPENDIX F

CALCULATION OF STANDARD DEVIATION

APPENDIX F

CALCULATION OF STANDARD DEVIATION

$$S.D. = \sqrt{\frac{\Sigma\ (x - \mu)^2}{n - 1}}$$

S.D. = Standard Deviation

Σ = Sum of measured data

x = Measured data

μ = Mean of the measurements

n = Number of measurements

APPENDIX G

CALCULATION OF SEED MOISTURE

APPENDIX G

CALCULATION OF SEED MOISTURE

$$\left[\frac{W_F - (W_o \times 0.8747)}{W_o \times 0.8747}\right] 100 = \text{g } H_2O/100 \text{ g dry matter}$$

W_F = Final corn sample weight

W_o = Original corn sample weight

0.8747 = Original dry matter weight of 1 gram of corn seed

LIST OF REFERENCES

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Aldrich, S.R. and Leng, E.R. 1969. Modern Corn Production. F & W Publishing Corp., Cincinnati, OH.

AOAC. 1980. Official Methods of Analysis, 13th Ed. Association of Official Analytical Chemists, Washinton, DC.

Bass, L.N. and Clark, D.C. 1967. Varietal Difference in Longevity of Vegetable Seed and Their Response to Various Storage Conditions. Proceedings, American Society Horticulture Science. 91:521.

Barton, L.V. 1961. Seed Preservation and Longevity. Interscience Publishers, NY.

Bender, F.E., Douglas, L.W. and Kramer, A. 1982. Statistical Methods for Food and Agriculture. AVI, Connecticut.

Bockhart, A.S., Rogers, J.S. and Richmond, T.R. 1969. Effects of Various Storage Conditions on Longevity of Cotton, Corn and Sorghum Seeds. Crop Science, Vol. 9, March-April 1969.

Brooker, D., Bakker-Arkema, F. and Hall, C. 1974. Drying Cereal Grains, 3rd printing, 1981. AVI Publishing company, Westport, CT.

Canode, C.L. 1972. Germination of Grass Seeds as Influenced by Storage Conditions. Crop Science. Jan.-Feb. 1972, 79:80.

Cavers, P.B. 1974. Germination Polymorphism in Rumex Crispers: The Effects of Different Storage Conditions on Germination Responses of Seeds Collected from Individual Plants. Canadian Journal of Botany. 52:575-583, March 1974.

Christensen, C., ed. 1974. Storage of Cereal Grains and Their Products. 2nd ed. American Association of Cereal Chemists, Inc. St. Paul, MN.

Chapman, S. and Carter, L. 1976. Crop Production Principles and Practices. W. H. Greeman and Co., San Francisco, CA.

Copeland, L.O. 1976. Principles of Seed Science and Technology. Burgess, Minneapolis, MN.

Copeland, L.O. 1977. High Quality Seed. Extension Bulletin E-1161. Cooperative Extension Service, Michigan State University. East Lansing, MI.

Cromarty, A.S., Ellis, R.H. and Roberts, E.H. 1982. The Design of Seed Storage Facilities for Genetic Conservation. International Board for Plant Genetics Resources. Rome.

Das, N.D., Babu, D.V.N. and Setty, P.T. 1975. Seed Treatment and Its Effect on Storage, Germination and Seedling Height. Pesticides. Jan. 1975. p. 47.

Delorit, R.J., Greub, L.J. and Ahlgren, H.L. 1974. Crop Production, 4th ed. Prentice Hall. NJ.

Douglas, J.E. 1980. Successful Seed Programs: A Planning and Management Guide. Westview Press. Boulder, CO.

Erdmann, M., Rossman, E. and Robertson, L. 1981. Profitable Corn Production in Michigan. Cooperative Extension Service, Michigan State University. East Lansing, MI.

Finney, E.E., ed. 1981. CRC Handbook of Transportation and Marketing in Agriculture, Vol. II. CRC Press Inc., Boca Raton, FL.

Grabe, D.F. and Isely, D. 1969. Seed Storage in Moisture Resistant Package. Seed World. 1969, 104(2):2-5.

Hanlon, J. 1984. Handbook of Package Engineering, 2nd ed. McGraw Hill Book Co., New York.

Harrington, J.F. 1960. Drying, Storing, Packaging to Maintain Germination Vigor, Part I. Seedsmens Digest. Jan. 1960, p. 16.

Hellum, A.K. 1973. Seed Storage and Germination of Block Poplar. Canadian Journal of Plant Science. Jan. 1973, p. 227-228.

Isely, D. and Bass, L.N. 1959. Seed and Packaging Material. Proceedings of the 14th Hybrid Corn Industry Research Conference. p. 101.

Jain, N.K. and Saha, J.R. 1971. Effect of Storage Length on Seed Germination in Jute. Journal of Agronomy. July-August, 1971, p. 636-637.

Jugenheimer, R.W. 1976. Improvement of Seed production and Uses. Wiley-Interscience Publication. New York.

Justice, O.L. and Bass, L.N. 1978. Principles and Practices of Seed Storage . Agriculture Handbook No. 506. U.S. Government Printing Office. Washington, DC.

Mangelshorf, P. 1974. Corn, Its Origin, Evolution and Improvement. The Belknap Press of Harvard University Press. Cambridge, MA.

Neal, N.P. and Davis, J.R. 1956. Seed Viability of Corn Inbred Lines as Influenced by Age and Conditions of Storage. Argon Journa. 48:383.

Singh, J.N. and Maurya, M.L. 1972. Effect of Storage Conditions on Germination of Soybean Seeds. Bulletin of Grain Technology. Sept. 1972. p. 158-167.

Srivastava, K. and Sareen, K. 1972. Germination of Soybean Seeds as Affected by different Storage Conditions. Bulletin of Grain Technology. Sept. 1972, p. 190-196.

Thompson, J.R. 1979. An Introduction to Seed Technology. John Wiley and Sons. New York.

Whitney, T. 1980. New Package Gives Seeds a Longer Life. Canadian Packaging. March 1980. p. 25.

Wilton, A.C. and Rogler, G.A. 1978. Longevity of Alfalfa Seed Storage and Germination. Crop Science. Nov.-Dec. 1978, p. 1091-1093.