EFFECTS OF PHYSIOLOGICAL QUALITY OF SEEDS ON TOTAL GERMINATION, RATE OF GERMINATION, AND SEEDLING VIGOR

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AN ABSTRACT

Submitted to the College of Agriculture
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ABSTRACT

This study was undertaken to investigate further the effects of a decline in the physiological quality of seeds on total germination, rate of germination, and particularly the vigor of the resulting seedlings.

Barley, beans, corn, and wheat seeds (also alfalfa to a limited extent) were subjected to various types and amounts of abuse after which germination tests were conducted. Injury was inflicted by mechanical beating, high drying temperatures, and storage at high relative humidities for varying lengths of time.

The effects on total percentage germination, rate of germination, and vigor as measured by the average seedling weight was found to depend both on the type of seed involved and the nature of the abuse to which they were subjected. No close correlation was found between these measurements, or between any of these measurements and the tetrazolium test.

Injury to barley was detectable first by a reduction in the rate of germination, whereas, injury to beans caused a reduction in total germination first. In general, the seedling weight was reduced first in injured corn, and the rate of germination first in injured wheat.

It is suggested that the characteristic or measurement that is known to be affected first in a given type of seed could be used as a measure of the quality of the seed.

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INTRODUCTION

It has long been recognized that "good" seed is at the very foundation of good agriculture. Seed of high quality must have high genetic and physiological quality in addition to being well processed mechanically.

Plant breeders have been able to improve the genetic quality of most of the agricultural crops and Industry is constantly supplying Agriculture with more efficient machinery for harvesting and processing crop seeds. While this progress is highly desirable, it is essential that the importance of the physiological quality of seeds not be overlooked.

Environmental conditions can modify or change the physiological quality of a seed at any time between the formation of the embryo on the parent plant and the germination of that seed when placed under conditions favorable for germination. It is extremely important, then, to know how "alive" seeds really are before they are planted. (Everson, 17, Moore, 25.) This means that information is needed on the "vitality" as well as the viability of the seeds. While this need has been recognized, there is as yet no generally applicable, easy, and quick method of determining the vitality of seeds. In most of the work that has been done with the storage and viability of seeds, percentage of germination has been used as the sole measure by which to make comparisons between seed lots. It may be that the vigor of the seedlings after emergence would be a better criterion of the quality of the seed than the percentage germination per se.

This study was undertaken to investigate further the effect of a decline in the physiological quality of seeds on total germination, rate of germination, and particularly the vigor of the seedlings. The tetrazolium "vigor" test was also used to a limited extent.

LITERATURE REVIEW

I. GENERAL

In an historical sketch Brown (9) points out that seed-testing as a service to those who wished to know something of seed quality was first undertaken in Denmark and Germany in 1869. In the United States little progress was made in this field until 1876 when Dr. E. H. Jenkins, on his return from Europe, emphasized the value of seed-testing.

In an extensive review of the literature dealing with recent developments in seed technology, Porter (28) states that while in the early work with seeds the major emphasis was on seed purity, it was not long until it was recognized that the measurement of seed viability was of equal importance. It is now generally recognized that the primary purpose of a seed germination test is to determine the ability of seeds to grow and produce normal plants. This is done under optimum conditions and has come to be recognized as a measure of seed viability. Porter (28) points out that many investigators have compared the laboratory and field germination of seeds, and that the results seem to indicate that there is a close correlation between laboratory and field results only if the field conditions are favorable for germination.

In order to bring uniformity into the evaluation of seedlings that result from laboratory germination tests the Association of Official Seed Analysts and the United States

Department of Agriculture have adopted the following definition of germination: "In seed laboratory practice, germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce normal plants under favorable conditions."

The real purpose of seed testing, according to Isely (23), is to determine the planting value of seed. This value is determined not only by viability, but also by the vigor of the seedling.

Working with flower seeds, Heit (21) found that seed "vitality" was an equally or sometimes a more important factor in field seedling stands and eventual flower performance than the actual percentage of laboratory germination.

Isely (22) defines "vigor" as the sum total of all seed attributes which favor stand establishment under unfavorable field conditions. He feels that a vigor test should be prognosticated in terms of field conditions which are critical with respect to the seed kind involved. Vigor in the field, he states, is primarily a function of the seed-micro-organism inter-relationship.

The "vigor of life", Moore (25) states, is at its greatest level when the seed first matures. After maturity, however, life becomes less and less vigorous as the never-ceasing aging process moves onward toward death.

II. FACTORS AFFECTING SEED VIABILITY AND VITALITY

Boswell et al (7) state that at a given temperature, the moisture content of the seed determines its longevity and that the moisture content in turn depends on the humidity of the surrounding air.

Working with vegetable seeds they found that deterioration of any one kind of seed at one temperature was, in general, proportional to the humidity of storage, or the moisture content of the seed. Different kinds of seeds responded very differently to any specific humidity level or moisture content of the seeds, and to temperature of storage.

Barton (1) and Barton and Crocker (2) found, in addition, that seeds of high initial vitality were much more resistant to unfavorable storage humidities and temperatures than were those of low initial vitality. The deterioration of a seed lot, once initiated, proceeded rapidly to the death of all the seeds under unfavorable storage conditions, but was not marked under favorable conditions.

From work with tomato seeds stored for 13 years under dry conditions at -5°C, Barton and Garman (3) concluded that storage conditions had a greater effect on the seedlings than the age of the seed.

Tervet (32) working with soybeans found that the percentage of seeds infected by fungi (especially Aspergillus spp.) increased as the moisture content of the seed increased, and that the viability and vigor of the high-moisture content seed, (above about 13 per cent) rapidly decreased. In addition, it was found that severe retardation in seedling growth resulted from storage conditions favoring the development of fungi, but that fungicidal treatment of the seeds at the time of planting improved the vigor and stand of plants.

Dungan and Koehler (15) found that aging, under good storage conditions, markedly reduced the prevalence of viable fungi in infected seed corn. Despite this decrease in viable fungi, they found that plants from old seed lacked the vigor of plants from new seed.

Moore (25) states that even under favorable conditions, as seeds advance in age, (a) they germinate over a longer time, giving rise to seedlings of uneven size; (b) the percentage germination decreases; (c) the seedlings lack somewhat in vigor and grow slowly; (d) the percentage of abnormal seedlings increases, and (e) more seedlings succumb to disease.

Of the possible reasons that have been suggested for the fall in vitality of seeds in dry storage, Crocker (12,13) and D'Amato (14) consider the accumulation of substances in the seed which are toxic to the delicate mechanism of the cell nucleus and/or the gradual degeneration of the nuclei of the cells of the embryo as being the most likely.

D'Amato (14), in critically reviewing the literature on the physiological and genetic aspects of seed aging, presents the following facts;-

1. Seedlings from aged seeds may show one or more of the following aberrations:

   (a) Necrosis of the meristems (particularly of the radicle),

   (b) Production of adventitious roots from the hypocotylar and/or epicotylar regions,

   (c) Inability to form chlorophyll,

   (d) Precocious death of some seedlings due, either to some physiological defect, or to some possible action of toxic metabolites formed during the aging process, and made soluble at germination.

2. Observed structural changes in the meristems are mostly of a chromosome type. A sharp increase in the rate of chromosome aberrations generally parallels a sharp decrease in seed germinability.

3. Autotoxic, automutagenic, toxic or mutagenic actions may be exhibited by extracts of aged seeds.

He gives the following as evidences supporting the idea of an "upset of the nuclear mechanism"-

(a) the occurrence of mutations during dormancy,

(b) the reactions of the shoot and radicle apices of the embryo to the "mutation-inducing conditions" paralleled by an identical behavior of the same organs during irradication of dormant fresh seeds;

(c) the established occurrence of mutagenic compounds in aged seed, and

(d) the relationship between the increase in mutation frequency and the decrease in seed germinability.

In germinating hybrid seed corn under "cold test" conditions, Neptune (27) found wide differences between samples of the same hybrid produced by different seed-growers. He felt that a small seed-producer with limited mechanical processing equipment was capable of producing seed with a better cold-test performance than larger seed-growers with a more highly mechanized process.

Funk (19) reporting on studies conducted at the New Jersey Agricultural Experiment Station, states that mechanical injury to seed corn may cause reduced yield in the next year's crop. Most of the variation in yield (58 per cent) in the tests that were conducted was found to be associated with seed injury, even though all the seed had been treated with a fungicide. Pericarp injury in eight commercial lots of hybrid seed corn that were examined was found to range from 25.5 per cent to 99.5 per cent.

Solorio (30), working with pea bean seed, found that in all of the 41 strains of beans used, the percentage mechanical damage varied inversely with the level of seed moisture. It was concluded that the abnormalities in the seedlings, as well as the differences in germination, vigor, and average weight per plant from seeds from the three levels of moisture, and those of the control, were to be attributed to mechanical injury. The number of normal seedlings and the percentage germination of the beaten seeds decreased as the content of seed moisture decreased.

Working with methyl bromide as a fumigant, Cobb (10) found that different kinds of crop seeds varied considerably in their reactivity with it. Generally the seedlings from fumigated seed appeared to be normal, differing from the unfumigated controls only in their slower emergence and slower growth rates.

Zavitz (34), in summarizing his work with different seed sizes of various annual crops, states that in every instance the larger seed produced more vigorous seedlings and a greater yield. The differences were significant when the same weight of seed was used and were much greater when the same number of seeds was used per acre.

In a report on the influence of seed size on seedling growth and yielding capacity of plants, Brenchley (8) states that field experiments indicate that with annual plants, at least, better crops are usually obtained by the use of heavy seed in preference to light, whether equal numbers of bushels, or equal numbers of seeds are sown per acre. The efficiency index falls gradually as the weight of the seed rises, and with prolonged periods of growth, this tends ultimately to counter-balance the advantage gained by plants from the heavier seeds. With annual crops, however, harvesting generally occurs before the equilibrium is reached, leaving the advantage with the heavier seeds.

Working with alfalfa, Erickson (16) found that germination, seedling vigor, and seedling weight were all directly associated with seed size, but that plants produced from initially weaker seedlings tended to overcome this disadvantage in about four months' time.

Black (5), using different sizes of subterranean clover seed, found that when plants were spaced so as to eliminate competition, the dry weights of the plants were proportional to seed weights. He found the same to be true during the early part of the season for plants grown in swards, but when the swards reached a leaf area index of about 4 (total leaf area equalled four times the soil area) a reduction in growth rate occurred. This critical leaf area index was reached first by large seed swards. Thus, there was a period in which the dry weights came to parity so that on the final sampling occasion there was no significant difference between the dry weight of the swards from the three seed size groups. (This assumes no competition from weeds or other species).

From a study of the development and fate of individual plants grown from contrasting seed sizes in swards, Black (6) found that where mixed (large and small) seed was used, there was a steady drop in the number of plants (about 30 per cent) over the whole period, and that only plants from small seeds died. The proportion of leaf area held by the small seed plants and the amount of incident light energy they absorbed dropped considerably during the growing period. It was concluded that the disappearance in the mixture of the plants from small seed was due to shading from large seed plants.

III. TESTS FOR SEED VIABILITY AND VITALITY

Svien and Isely (31) state that ordinary germination tests made under favorable conditions do not always suffice to detect differences between seed lots. Lots with approximately the same percentage germination may differ markedly in their ability to grow under adverse conditions, and hence in their agricultural value.

Working with heat damaged barley, French (18) found that amylose formation in the isolated embryo was indicative of viability. The amount of amylose formed in a given time (8 hours) was found to be roughly proportional to the fresh weight of the seedlings, to the increase in fresh weight of the seedlings, and to the seedling height at five days.

Moore (25) suggests the use of (a) the cold test, (b) germination speed, and (c) the vacuum treatment prior to testing, as possible aids in determining vigor. From his work with the cold-test germination of hybrid seed corn, Neptune (27) found that the association between cold-test germination and seedling vigor was inconsistent, and that the correlations of germination and seedling vigor with yield and maturity did not indicate that there was any consistent relationship among these characteristics.

Moore and Smith (26) state that while low germination frequently indicates seed weakness, seed vigor is more difficult to ascertain and at best can only be roughly estimated. The cold test, they feel, gives a fairly good indication of the probable field performance of a seed lot.

The tetrazolium test is claimed by Porter (28) and Moore and Smith (26) to be superior to other tests employing dyes or reducible salts, and they feel it has considerable practical application. The latter state that tetrazolium not only points out which seeds are alive, but also points out the trouble spots in both live and dead seeds. It divides the seeds into three classes - (a) the good, live seed, (b) weak or damaged seeds that will grow in the laboratory but not in the field, and (c) the aged, injured, or diseased seeds that can never grow.

Cobb (11), working with seeds that had been fumigated with methyl bromide, found that the tetrazolium test did not show the decline in viability during fumigation or in post fumigation storage.

It was found by Bennet and Loomis (4) that tetrazolium did not give accurate results when used on freshly frozen immature corn, but that freezing damage could be determined if tests were made after the corn had been stored for some time after freezing.

Rice (29) states that the tetrazolium test was effective in evaluating the vigor of naturally aged corn seed after unfavorable storage, but that it was unsatisfactory as a vigor test on mechanically damaged seed stored under unfavorable conditions.

MATERIALS AND METHODS

I. SEEDS USED

In this study the following types and varieties of seeds were used:

(a) Ranger Alfalfa

(b) Hudson and Moore Barley

(c) Michelite Pea Beans

(d) Hybrid Corn - (i) Double cross - Mich. 425
(ii) Single cross - (WF9 x OH 51A)

(e) Genesee Wheat

Some of the seed lots were obtained from the University farm and others from the Michigan Crop Improvement Association.

In some of the experiments the seed lots were used as they were and in those instances the comparisons were between different lots. In most of the experiments, however, a seed lot was divided into several samples which were then treated in different ways before being germinated.

II. SEED TREATMENTS

The treatments used were ones which are known to injure seeds under ordinary farming conditions, namely, mechanical abuse, storage at high relative humidities, and high drying temperatures. The purpose of this study was not to investigate these treatments per se, but the treatments were used to provide material with various types and varying amounts of injury so that a study could be made of the effects of the injury on the percentage and rate of germination, as well as the vigor of the resulting seedlings.

A. Mechanical Injury

Mechanical injury was inflicted by putting the seed samples through a "beater" which was used by Solorio (30) to mechanically injure pea bean seeds. The amount of abuse was varied by putting the seeds through the beater a varying number of times and at various speeds. In the case of beans, corn, and wheat, only seeds which showed no visible injury were used in the germination tests. It was not possible to detect injury to the barley seed because of the presence of the palea and lemma. The palea and lemma on most of the seeds, however, were damaged extensively and seeds showing this damage were used in the germination tests.

The designation "Beaten x 6F" indicates that the sample was put through the beater six times at the fastest of the three speeds used (approximately 1000 r.p.m.). "S" indicates the slow speed (500 r.p.m.) was used, and "M" that the intermediate speed was used (750 r.p.m.).

B. Heat Injury

Some samples of barley, corn, and wheat were dried at different temperatures in an oven in the Farm Crops Laboratory. The drying temperatures ranged from 40°C to 70°C.

C. Storage Injury

Storage injury was caused by storing samples of seeds in two five-gallon containers at different relative humidities. The seeds were placed in cheese-cloth bags and hung from the lids of the containers. Samples were removed after 7, 15, and 19 weeks.

A relative humidity of approximately 75 per cent was maintained in the one container by placing beakers containing a saturated solution of sodium chlorate ($NaClO_3$) in the bottom of the container. In the other container a saturated solution of potassium bisulfate ($KHSO_4$) was used to maintain a relative humidity of approximately 86 per cent.

III. GERMINATION TESTS

The germination tests were conducted in a germinator, in soil in plastic flats in the laboratory, and in the field.

A. Germinator Tests

Samples of seeds germinated in the germinator were placed either on moist blotters in small plastic crispers ($4\frac{1}{2}$" x $4\frac{1}{2}$" x $1\frac{1}{4}$") or rolled in moist blotters and stood at an angle in dishes containing a little water.

B. Field Tests

Most of this research was conducted during the fall and winter and therefore only a limited number of field germination tests were possible. Rows 50 inches long and five inches apart were used. A hundred seeds were used per row for alfalfa and barley, and 50 seeds per row for corn and beans. The corn and beans were planted approximately $1\frac{1}{2}$ inches deep, the barley, $\frac{1}{2}$ inch deep, and the alfalfa, $\frac{1}{4}$ inch deep.

C. Laboratory Soil Tests

It was felt that conditions less favorable for germination than those provided by the germinator were desirable, and therfore the major portion of the germination tests was carried out in soil in plastic flats (11" x $7\frac{1}{2}$" x $2\frac{1}{4}$") in the laboratory. The beans and corn were planted approximately 1 inch deep and the barley and wheat $\frac{1}{2}$ inch deep. To prevent rapid drying out of the soil in the dry atmosphere of the laboratory during the winter months, the flats were placed in plastic bags until germination was complete. The temperature in the laboratory fluctuated between 73° and 78°F.

D. Cold Test

The cold test method was used to a limited extent. Seeds were planted in soil in plastic flats and after the flats had been put in plastic bags, they were placed in a cold chamber at 40°F for seven days. At the end of the seventh day the flats were placed on the laboratory desks and germination took place at room temperature (approximately 75°F).

E. Tetrazolium Tests

In addition to the germination tests, 2, 3, 5 - triphenyl tetrazolium chloride was used to find what agreement existed between the germination tests and the tetrazolium test. It was hoped that the tetrazolium would also give some indication of the nature and/or site of the injury in the seeds.

A 0.1 per cent solution of 2,3,5 triphenyl tetrazolium chloride was used for testing barley, corn, and wheat. A 1.0 per cent solution was used for beans. The seeds were soaked in water for approximately 15 hours before being subjected to the test. After soaking, the grains were bisected longitudinally and one half of each kernel was placed in the tetrazolium solution for 45 minutes at 40°C. The readings were then made. The beans were left in the solution for four hours at 40°C, after which the seed coats were removed and the readings made. (Grabe and Delouche, 20).

IV. FUNGICIDAL TREATMENT

Seeds used in germinator tests and in field tests were not treated with a fungicide. Seeds for about half the laboratory soil tests were treated with "Orthocide 75". This was done in order to try to eliminate some of the secondary damage caused by pathogens.

V. REPLICATIONS AND SAMPLE SIZES

Two replicates were used for tests conducted in the germinator. In the laboratory soil tests, two to four replicates were used and four to six replicates were used in the field germination tests.

In most of the experiments 50 seeds per sample were used. In some cases, however, 100 seeds were used and in a few cases 25 seeds were used.

VI. MEASUREMENTS

A. Germination

The seedlings that had emerged at certain intervals during the germination period were counted in order to determine the "rate" of emergence of the different samples. The final count was made at the time the plants were harvested and the percentage germination was then calculated.

B. Vigor

At an arbitrarily set time the seedlings were harvested and the fresh weight obtained. In some of the preliminary experiments the weights of the whole plants were obtained as well as those of the aerial portions. In some experiments, in addition to obtaining the total weights, the seedlings were weighed in groups of ten or twenty according to size.

Throughout this study the average seedling weight was used as a measure of vigor of the seedlings.

RESULTS

I. PRELIMINARY EXPERIMENTS

A. Alfalfa

A number of different lots of Ranger Alfalfa seed were used in an attempt to find out if there was a correlation between the germination percentage and the weight of the resulting seedlings.

The germination tests were carried out on moist blotters in plastic crispers in the germinator. The results did not show as wide a range in germination percentage as it was hoped they would. Because of this and also the fact that the different lots contained widely differing amounts of hard seed, the results were inconclusive, and alfalfa was not used extensively in later experiments.

One experiment was conducted in which three seed lots were separated into four seed sizes by means of hand screens. The results showed a correlation between seed size within a lot and the weight of the seedlings, but not between the percentage germination and weight of the seedlings or seed size. In each of the three lots the largest seeds produced the largest seedlings.

Working with alfalfa, Erickson (16) found that germination as well as seedling weight was directly associated with seed size.

B. Corn

Five lots of seed (not Mich. 425 or (WF9 x OH 51A)) ranging from one to seven years in age were used in a germination test carried out in the germinator. These lots showed marked differences in rate of germination and seedling weight even though the lowest germination percentage was 87 per cent.

Samples from the same seed lots were also used in a field germination test. A wide variation in rate of germination and weight of seedlings was again obtained, but in this experiment the germination percentage varied from 40 to 96 per cent. Almost optimum germination conditions prevailed during the test.

It was recognized that some of the differences obtained both with the corn and alfalfa could have been due to variety, or the conditions under which different lots were produced, and not to aging or physiological deterioration. Therefore, it was decided that for all further experiments, comparisons would be made between differently treated samples of the same seed lot. The germination percentage, rate of germination, and average seedling weights were then calculated as percentages of the controls.

C. Comparison of Measurements

The weights of the whole plants and of only the aerial portions were obtained for bean samples grown in the field. A high correlation (+.96) was found between these measurements. Because of this high correlation and the correlation between different measurements on corn seedlings found by Rice (29), it was decided to use only the weights of the aerial portions of the seedlings in making comparisons between differently treated samples.

In a number of experiments the seedlings were arranged in order according to size and weighed in groups of 10 or 20 (from 50 or 100 original seeds). A correlation of from .75 to .90 was found between the weights of the size groups of the control and corresponding size groups of the various treatments. A high correlation (.90 for corn) was also found between the average weight per 10 seedlings and the weight of the ten largest seedlings.

In the presentation of the results of this study, all comparisons between treatments were made on the basis of average seedling weight. This average weight was obtained by dividing the total weight of seedlings by the number of seedlings that emerged.

II. EXPERIMENTS WITH MECHANICALLY INJURED SEED

A. Germination Tests

Alfalfa - Several samples of three different seed lots were put through the mechanical beater a varying number of times. These seeds were then germinated on blotters in plastic crispers in the germinator, along with samples of unbeaten seed.

The results showed no significant reduction in seedling weight whereas there was a considerable increase in both percentage germination and rate of germination for the most severely beaten samples. It seems apparent that the beater, instead of damaging the seed, acted as a scarifier and reduced the percentage of hard seed in the samples.

Barley - Several samples of a 1958 Hudson Barley seed lot were mechanically beaten up to 12 times at the "fast" speed. The damage was so extensive that it was necessary to use some seeds that showed visible damage to the palea and lemma. It was not possible to ascertain whether or not the seed itself had been injured.

Samples that had been beaten four, six, eight, and twelve times were germinated in flats in the laboratory. When the first count of seedlings was made, it was found that the rate of germination from some of the beaten samples was higher than that of the control. (See Figure 7A, page 40.)

The beating had no detrimental effect on the percentage germination. The different beating treatments caused some variation in the average seedling weights for different samples, but there was no definite decrease in average weight. (See Figure 1, page 31.)

A sample that had been beaten six times and then germinated in the germinator was found to be equal to the control in percentage germination, rate of germination, and average seedling weight. Some of the same seed was used in a field germination test and similar results were obtained.

Beans - Samples from several different seed lots were beaten. The amount of visible injury suffered by different samples was inversely related to the moisture content of the seeds at the time of beating. (Solorio, 30). Only seeds showing no visible injury were used in the germination tests.

The germination tests were carried out in flats in the laboratory. The rate of germination of the dry samples was reduced considerably by beating. Samples that had been stored at 86 per cent relative humidity for seven weeks and then beaten showed an improvement in rate of germination. (See Figure 8A, page 40.)

The percentage germination was reduced considerably by mechanical injury. The average weight of seedlings fell significantly also, but not to the same extent as the percentage germination. (See Figure 1, page 31.) The number of abnormal seedlings increased with an increase in mechanical injury.

Germination tests conducted in the germinator showed similar but less marked differences while field tests showed more marked differences.

Corn - Samples from two seed lots which had been in dry storage were beaten four, six, and eight times respectively. In addition, a sample that had been stored for seven weeks at 75 per cent relative humidity was beaten six times and one that had been stored for seven weeks at 86 per cent relative humidity was beaten four times.

Germination tests carried out in flats in the laboratory showed that beating generally had little effect on either the percentage germination or the rate of germination. In the case of seed stored at 75 per cent relative humidity for seven weeks and then beaten, the percentage germination was reduced to 88 per cent of that of the control. For the same sample the average seedling weight was reduced to 66 per cent of that of the control. The seedling weights for the other beaten samples, except the one beaten only four times, were reduced approximately the same amount. (See Figure 1, page 31.) Germination tests carried out in the germinator and in the field showed essentially the same results.

Tests carried out with seeds that had not been treated with a fungicide showed wider differences than those where treated seeds were used. Secondary injury from pathogens was probably responsible for some of the reduction in vigor of seedlings from beaten seed. (See Figure 3, page 32.)

Three samples that had been mechanically injured were included in a cold test in which half of the replicates were treated with a fungicide (Orthocide 75). The results were very similar to those obtained in the other germination tests. The treated replicates showed an increase in average seedling weight over the untreated, but the percentage germination was not affected by the fungicidal treatment. These results were analysed statistically and it was found that there were highly significant differences both between treated and untreated, and between the controls and the mechanically injured samples.

TABLE I

ANALYSIS OF VARIANCE OF CORN GERMINATION TEST

	D.F.	SS.	M.S.	F.
Total	19	16.88	-	-
Beatings	4	8.33	2.08	6.80*
Treatments	1	4.37	4.37	14.28*
Beatings x Tr.	4)	3.54)	-	-
Error	10)	.64)	-	-
	14	4.28	.306	

Wheat - Samples of wheat were beaten four, six, eight, and twelve times. Germination tests were carried out in flats in the laboratory using only seeds which showed no visible injury.

The mechanical injury had no noticeable effect on the rate of germination. The percentage germination was rather variable, but the average seedling weight was reduced signigicantly by mechanical injury to the seeds. Beating the seed four and twelve times reduced the average seedling weights to 84 and 70 per cent, respectively, of that of the control.

B. Tetrazolium Test

Mechanically injured corn could be distinguished from the control by the lighter red color of the embryo of the injured seed, but it was not possible to determine either the extent or the site of the injury by the tetrazolium test.

The tetrazolium test was used to compare two samples of seed which had been subjected to the same amount of beating, but, in the one case, the beating had been done four months before the test, and, in the other case, only a few days before the test. No difference was found between the two samples, but they could both be distinguished from the controls. (See Figure 11, page 43.)

It was impossible to distinguish between mechanical and heat injury by the tetrazolium test. Storage injury gave a wide variation of coloration within a sample and, therefore, could be distinguished from other types of injury by this lack of uniformity within a sample.

The results of tetrazolium tests carried out on mechanically injured wheat were very similar to those with corn. Beaten barley samples, however, could not be distinguished from the controls. This fact lends support to the suggestion that the barley seeds were, in fact, not injured.

Mechanically beaten bean seeds which showed no visible injury were subjected to the tetrazolium test. They stained a dark red and could not be distinguished from the controls on the basis of color. However, when the seed coats were removed at the time the readings were made, it was found that the cotyledons were broken into a number of pieces and, in many cases, the cotyledons were broken off of the embryos.

The injury in the case of the beans appears to have been purely mechanical, while in the case of corn and wheat, it was, atleast partly, physiological.

III. EXPERIMENTS WITH HEAT INJURED SEED

A. Germination Tests

Barley - Samples of a single barley seed lot with an initial moisture content of 15 per cent were dried at 50°C, 60°, and 70°C respectively. The seeds were germinated in plastic flats in the laboratory about three months after drying.

The results showed that high drying temperatures reduced the percentage germination, rate of germination, and average weight of the seedlings significantly. (See Figure 2, page 31, and 7B, page 40.)

Corn - Samples of four different corn seed lots were dried at temperatures between 40° and 70°C. The initial moisture content of the lots ranged from 18 per cent to 30 per cent. The seed lots with the highest initial moisture contents were injured the most by the higher drying temperatures.

The results from germination tests conducted in the germinator and also in flats in the laboratory showed that increasing the drying temperature sharply reduced percentage germination, rate of germination, and the average weight of the seedlings. (See Figures 2, page 31, and 9B, page 42.)

Under both laboratory germination conditions and cold test conditions treatment of the dried samples with a fungicide did not have any effect on the percentage germination or the vigor of the seedlings. This would seem to suggest that secondary injury from the presence of pathogens was not involved in the dried samples as was the case with mechanically injured samples. (See Figure 3, page 32.)

Wheat - Samples of a single wheat seed lot with an initial moisture content of 15 per cent were dried at 50°, 60°, and 70°C respectively. Germination tests were carried out in flats in the laboratory about three months after the samples had been dried. The results show that the drying temperature appeared to have more effect on the rate of germination of the wheat than on that of the barley. (See Figures 7B, page 40, and 10B, page 42.)

A drying temperature of 70°C was not as injurious to wheat as it was to barley and corn under the conditions of this experiment. The correlation between the decrease in germination percentage and the decrease in average weight of the seedlings was not as high for wheat as it was for barley and corn. (See Figure 2, page 31, and figure 4, page 32a.)

B. Tetrazolium Test

With barley, corn, and wheat it was possible to distinguish between the seeds dried at high temperatures and the controls by the lighter red color of the embryos of the dried seeds. It was not possible by the use of the tetrazolium test to determine the site of injury, nor to distinguish between heat injury, and mechanical injury. (See Figure 11A, page 43.)

Description of Treatments Shown in Figure 1

Barley and Wheat

2. Beaten x 4F
4. Beaten x 6F
6. Beaten x 8F
8. Beaten x 12F

Beans

1. Stored at 86% R.H. for 7 weeks, then beaten x 2F
3. Stored at 86% R.H. for 7 weeks, then beaten x 4F
4. Stored at 75% R.H. for 7 weeks, then beaten x 1F
5. Stored at 75% R.H. for 7 weeks then beaten x 2F
7. Beaten x 1F
8. Beaten x 2F

Corn

2. Beaten x 4F
4. Beaten x 6F
6. Stored at 75% R.H. for 7 weeks, then beaten x 6F
8. Beaten x 8F

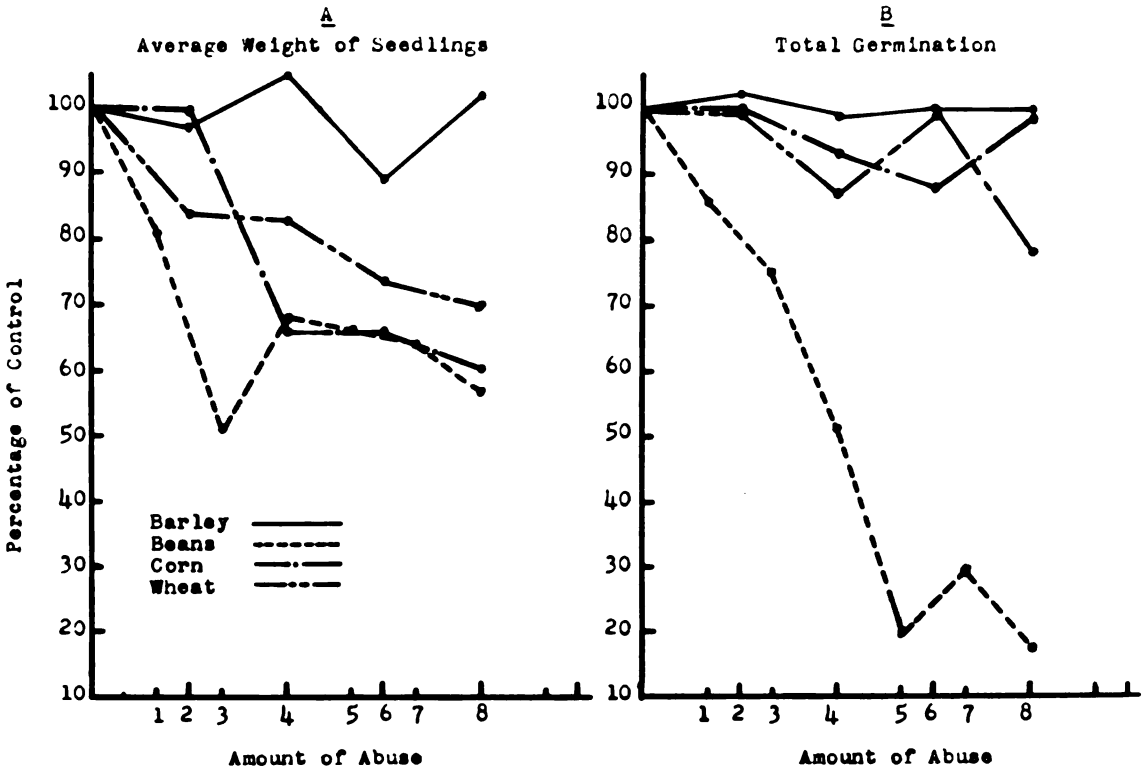


Figure 1. A comparison of the effects of mechanical injury on different types of seed. See opposite page for details of the amount of abuse.

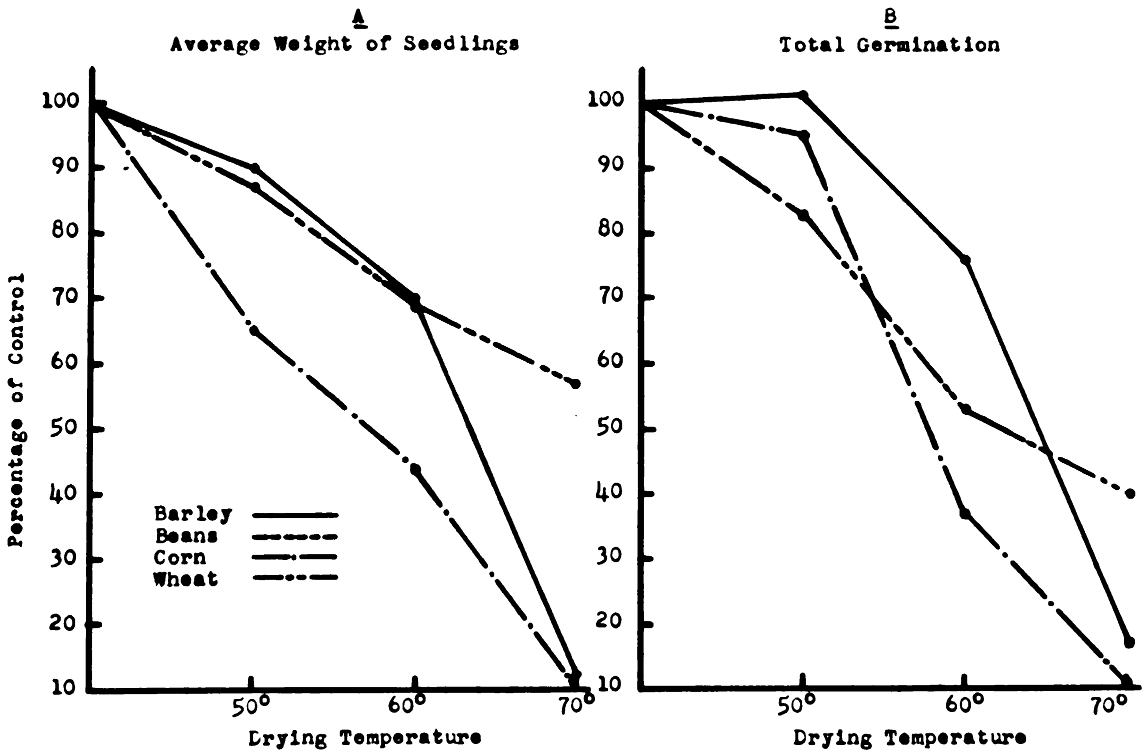
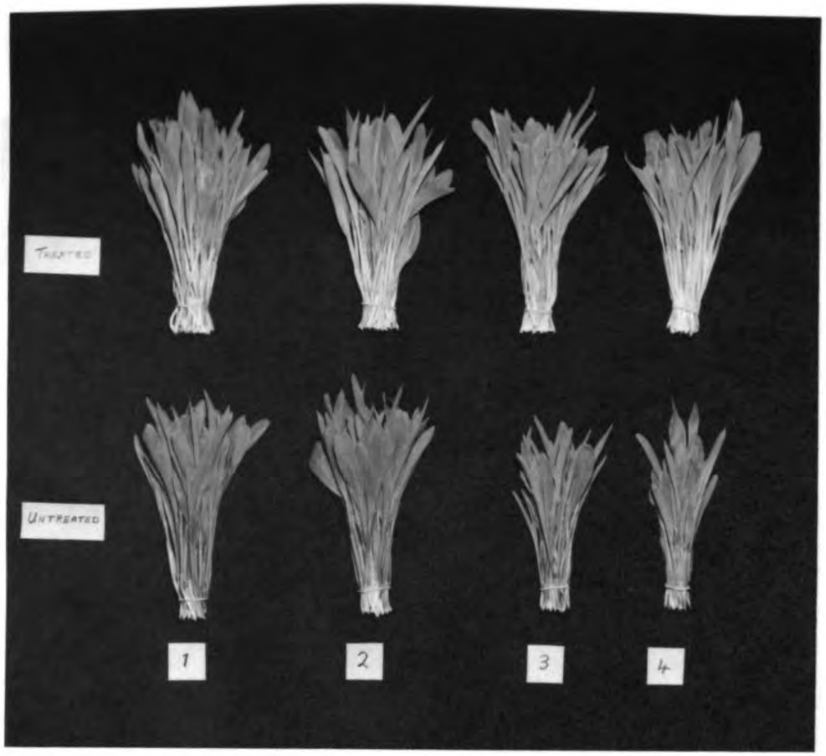
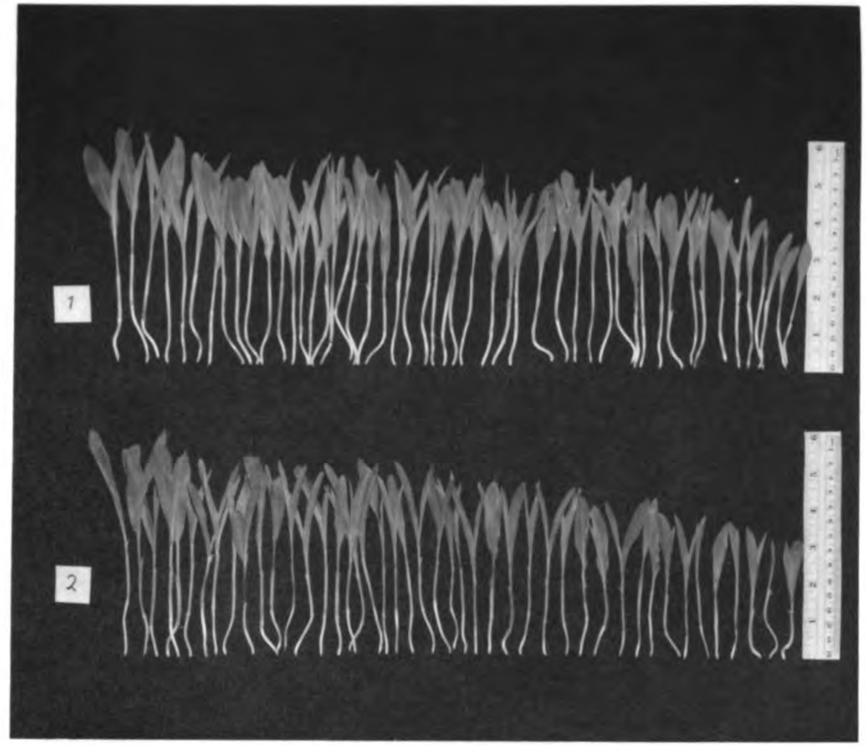


Figure 2. A comparison of the effects of heat injury on different types of seed. Drying temperatures given in degrees Centigrade.



A.

Top row treated with Fungicide
1. Control
2. Dried at 60°C
3. Mechanically beaten x 4F
4. Mechanically beaten x 8F



B.

Both treated with Fungicide
1. Control
2. Mechanically beaten x 8F

Figure 3. The effects of injury on corn seedlings grown from treated and untreated seeds. Seedlings from fifty seeds.

A.

Seedlings from 50 seeds
1. Control
2. Stored at 86% R.H. 7 weeks
3. Mechanically beaten x 6F
4. Mechanically beaten x 8F

B.

Seedlings from 25 seeds
1. Control
2. Dried at 60°C
3. Dried at 70°C

Figure 4. The effects of various types of injury on wheat seedlings.

IV. EXPERIMENTS WITH STORAGE-INJURED SEED

A. General

Barley, beans, corn, and wheat were used in these experiments. Samples from the same lots of seeds were placed in both the 75 per cent and 86 per cent relative humidity storage containers. Small samples were removed at the end of 7, 15, and 19 weeks respectively. These were air-dried and placed in airtight containers similar to those used for all other samples used in this study.

In some cases germination tests were carried out soon after the samples had been dried, while in others the samples were kept in dry storage for as long as three months before tests were carried out. All the germination tests were carried out in flats in the laboratory.

B. Germination Tests

Barley - Storage at 75 per cent relative humidity for as long as 19 weeks had no effect on either percentage germination or rate of germination. The average weight of the seedlings, however, increased with storage up to 19 weeks. (See Figure 5, page 38.)

Storage at 86 per cent relative humidity caused a gradual decrease in germination so that after 15 weeks the percentage germination was only 66 per cent of that of the control. After 19 weeks it was 75 per cent. This apparent improvement could probably be accounted for by the fact that the 19-week samples were germinated within ten days of their removal from storage, whereas the 15-week samples had been stored dry for approximately 5 weeks.

The average weight of the seedlings increased by 12 per cent with storage for 15 weeks at 86 per cent relative humidity. After 19 weeks of storage, the average seedling weight was almost equal to that of the control. (See Figure 6A, page 38.) Rate of germination decreased with increasing length of time in storage at 86 per cent relative humidity. (See Figure 7C, page 40.)

Beans - Storage at 75 per cent relative humidity for as long as 19 weeks had no apparent effect on percentage germination or average weight of seedlings. (See Figure 6, page 38.) The rate of germination decreased slightly with increased storage time up to 19 weeks.

The effects of storage at 86 per cent relative humidity were noticeable after 7 weeks in storage, and were very marked after 15 weeks. At the end of the 19th week in storage germination percentage was zero.

The percentage germination decreased more rapidly than the average seedling weight. After 15 weeks in storage, germination was only 3 per cent of that of the control, while the average seedling weight was 55 per cent of that of the control. (See Figure 6, page 38.) After 7 weeks in storage at 86 per cent relative humidity, the rate of germination was reduced slightly. (See Figure 8B, page 40.)

Corn - Storage at 75 per cent relative humidity had practically no effect on the percentage germination or the rate of germination. The average seedling weight was reduced slightly, being 93 per cent of that of the controls after 19 weeks in storage. (See Figure 6, page 38.)

Seeds showed a considerable reduction in the rate of germination when stored for 15 or 19 weeks at 86 per cent relative humidity. The percentage germination also decreased, dropping to 83 and 85 per cent of that of the control after 15 and 19 weeks respectively. On the other hand, the average weight of the seedlings remained equal to that of the controls even after 19 weeks in storage. (See Figures 6, page 38, and 9C, page 42.)

Wheat - The rate of germination was increased slightly by storage at 75 per cent relative humidity for as long as 15 weeks, and after 19 weeks in storage it was approximately equal to that of the control. The percentage germination increased to 8 per cent above the control with storage for 15 weeks. After 19 weeks, it was still 4 per cent above the control. (See Figure 5B, page 38.)

Storage for 7 weeks at 75 per cent relative humidity increased the average weight of seedlings 12 per cent above that of the control. After 15 weeks it had dropped to 97 per cent, and after 19 weeks, to only 92 per cent of that of the control. (See Figure 5A, page 38.)

The percentage germination of seed stored at 86 per cent relative humidity was reduced very sharply. It was 60, 26, and 22 per cent of that of the control after 7, 15, and 19 weeks in storage, respectively. The decrease in percentage germination and rate of germination was much more rapid than the decrease in average seedling weight. (See Figure 6, page 38, and 10C, page 42.) After 7 weeks in storage at 86 per cent relative humidity, the average weight of seedlings did not show any decrease, but after 15 weeks, it had dropped to 81 per cent of that of the control, and after 19 weeks it was 84 per cent. (See Figure 6A, page 38.)

B. Tetrazolium Test

In these experiments the tetrazolium test was employed in order to try to determine the site and extent of injury caused by poor storage conditions.

The test was used on barley, beans, corn, and wheat seeds, but no definite staining pattern was found that would indicate the site of injury.

Bean seeds showed unstained or dead tissue in the radicle and/or the cotyledons. Seeds which had been stored for 15 weeks at 86 per cent relative humidity showed a very wide range of coloration. (See Figure 12B, page 43.)

With corn stored for 19 weeks at 86 per cent relative humidity, a wide range of coloration was found also, but it was not possible to detect definite dead areas. The number of seeds which had begun to deteriorate was much smaller than in the case of beans. This could explain the fact that the average weight of corn seedlings remained equal to that of the control while the percentage germination dropped to 85 per cent for seeds stored at 86 per cent relative humidity for 19 weeks. (See Figure 11B, page 43.)

Tests on barley and wheat gave results very similar to those obtained with corn.

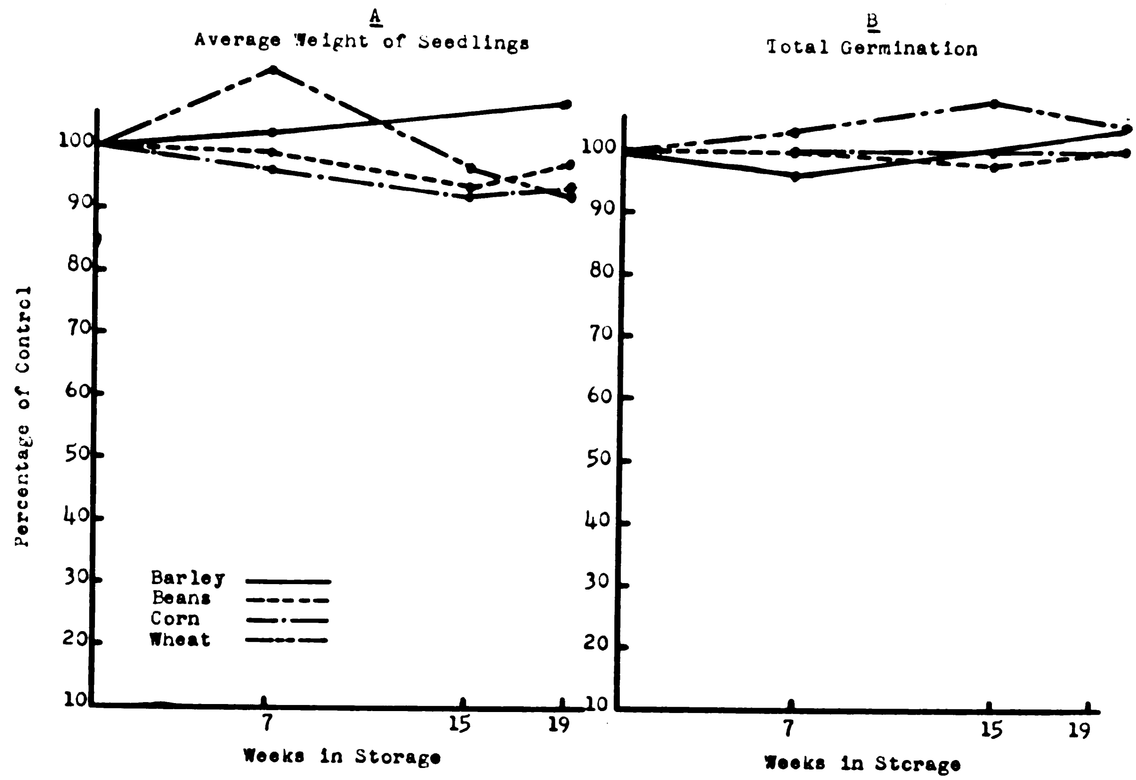


Figure 5. A comparison of the effects of storage at 75 per cent relative humidity on different types of seeds.

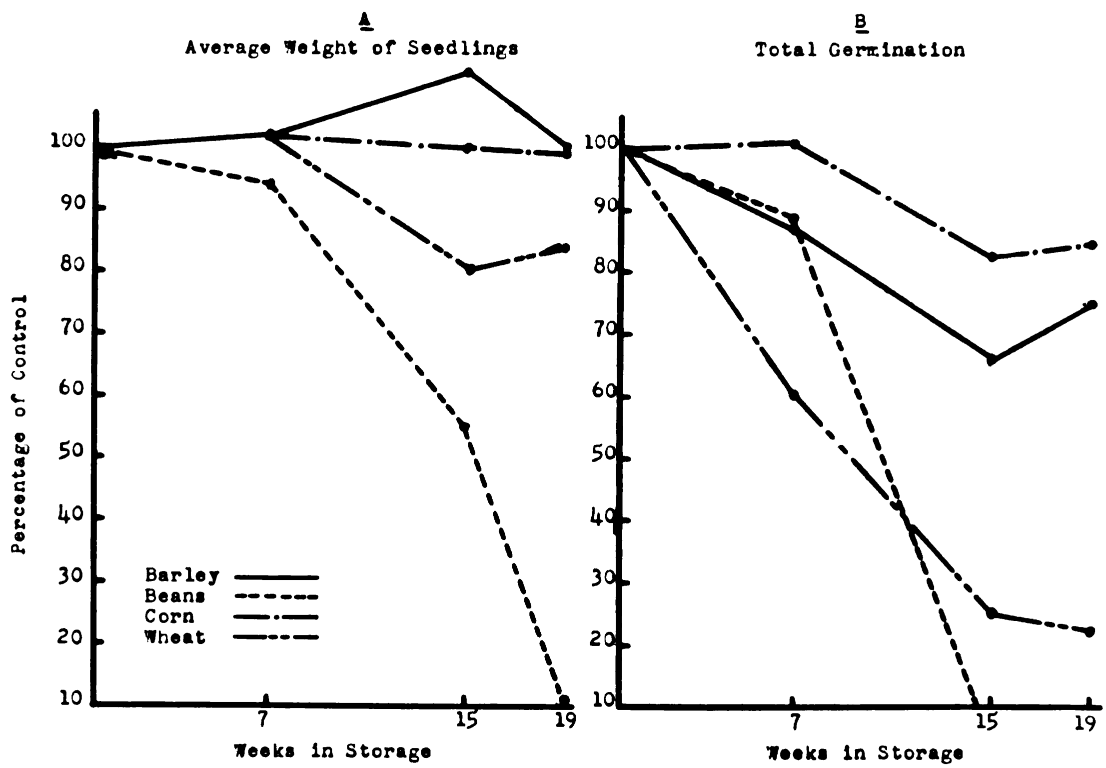


Figure 6. A comparison of the effects of storage at 86 per cent relative humidity on different types of seeds.

Description of Treatments Shown in Figure 7

Barley

Mechanical Abuse

1. Beaten x 4F
2. Beaten x 6F
3. Beaten x 12F

Drying Temperatures

1. 50°C
2. 60°C
3. 70°C

Weeks in Storage

1. Stored at 75% R.H. for 19 weeks
2. Stored at 86% R.H. for 7 weeks
3. Stored at 86% R.H. for 19 weeks

Description of Treatments Shown in Figure 8

Beans

Mechanical Abuse

1. Stored at 86% R.H. for 7 weeks then beaten x 2F

2. Stored at 75% R.H. for 7 weeks then beaten x 1F

3. Beaten x 1F

Weeks in Storage

1. Stored at 75% R.H. for 15 weeks
2. Stored at 86% R.H. for 7 weeks
3. Stored at 86% R.H. for 15 weeks

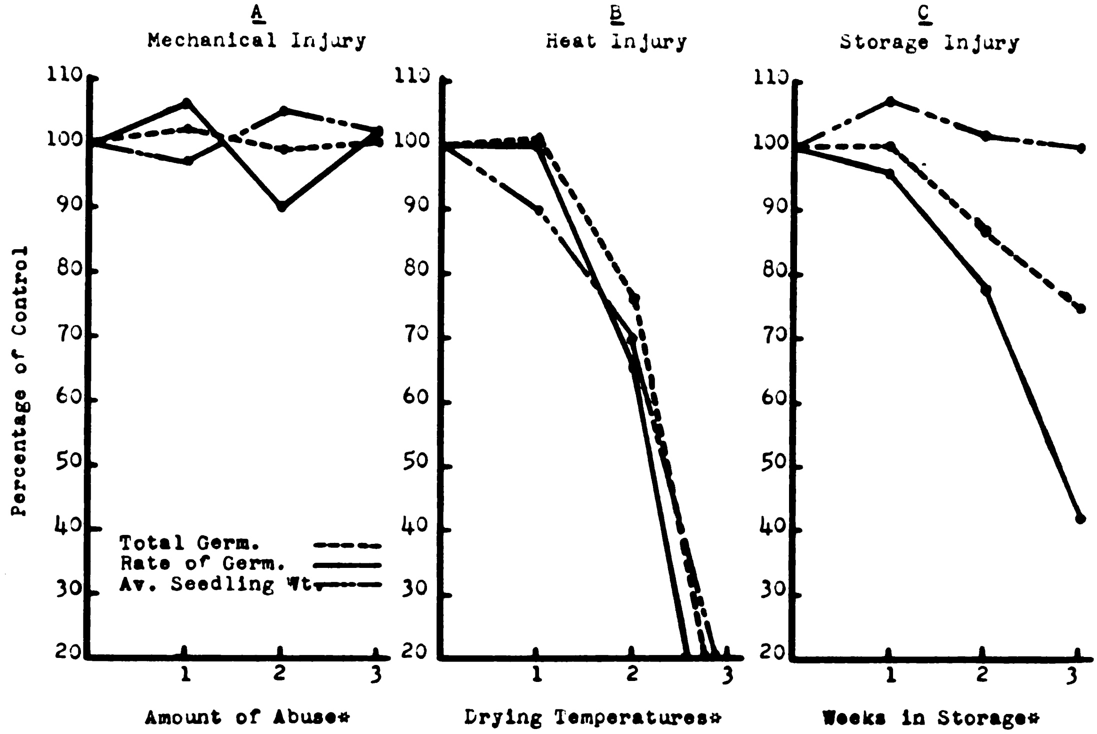


Figure 7. Barley - A comparison of the effects of injury on total germination, rate of germination, and average seedling weight.

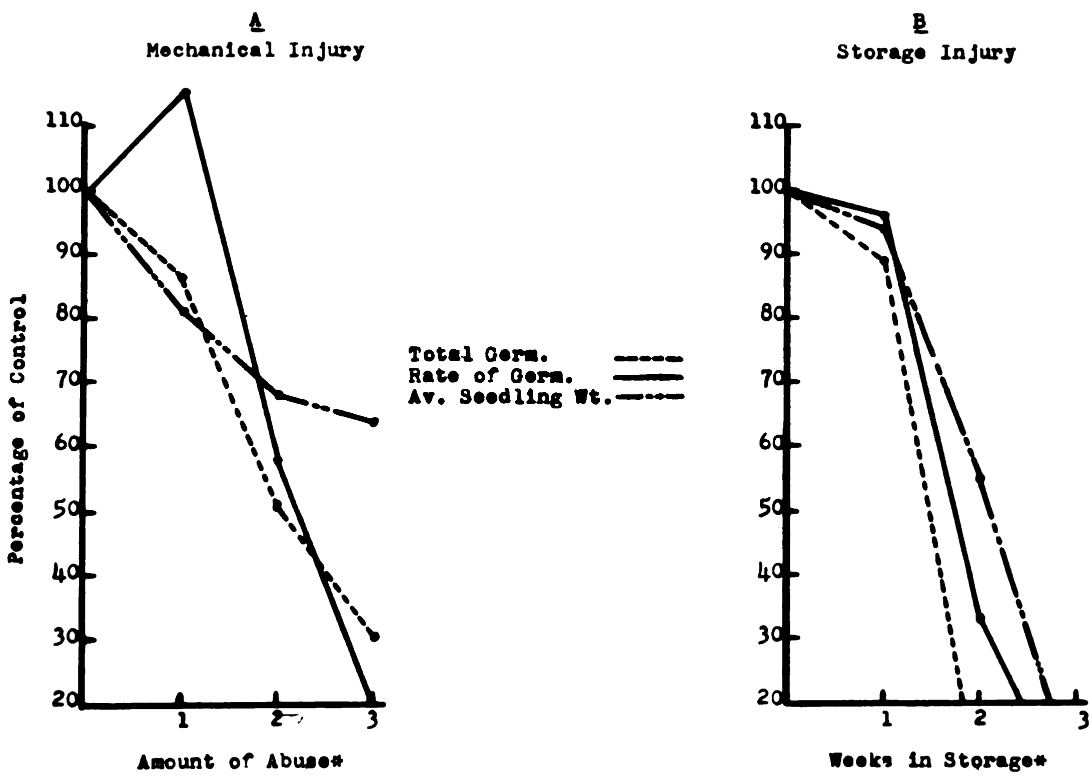


Figure 8. Beans - A comparison of the effects of injury on total germination, rate of germination, and average seedling weight.

*See opposite page for details

Description of Treatments Shown in Figure 9

Corn

Mechanical Abuse

1. Beaten x 4F
2. Beaten x 6F
3. Beaten x 8F

Drying Temperatures

1. 50°C
2. 60°C
3. 70°C

Weeks in Storage

1. Stored at 75% R.H. for 19 weeks
2. Stored at 86% R.H. for 7 weeks
3. Stored at 86% R.H. for 19 weeks

Description of Treatments Shown in Figure 10

Wheat

Mechanical Abuse

1. Beaten x 4F
2. Beaten x 6F
3. Beaten x 12F

Drying Temperatures

1. 50°C
2. 60°C
3. 70°C

Weeks in Storage

1. Stored at 75% R.H. for 19 weeks
2. Stored at 86% R.H. for 7 weeks
3. Stored at 86% R.H. for 19 weeks

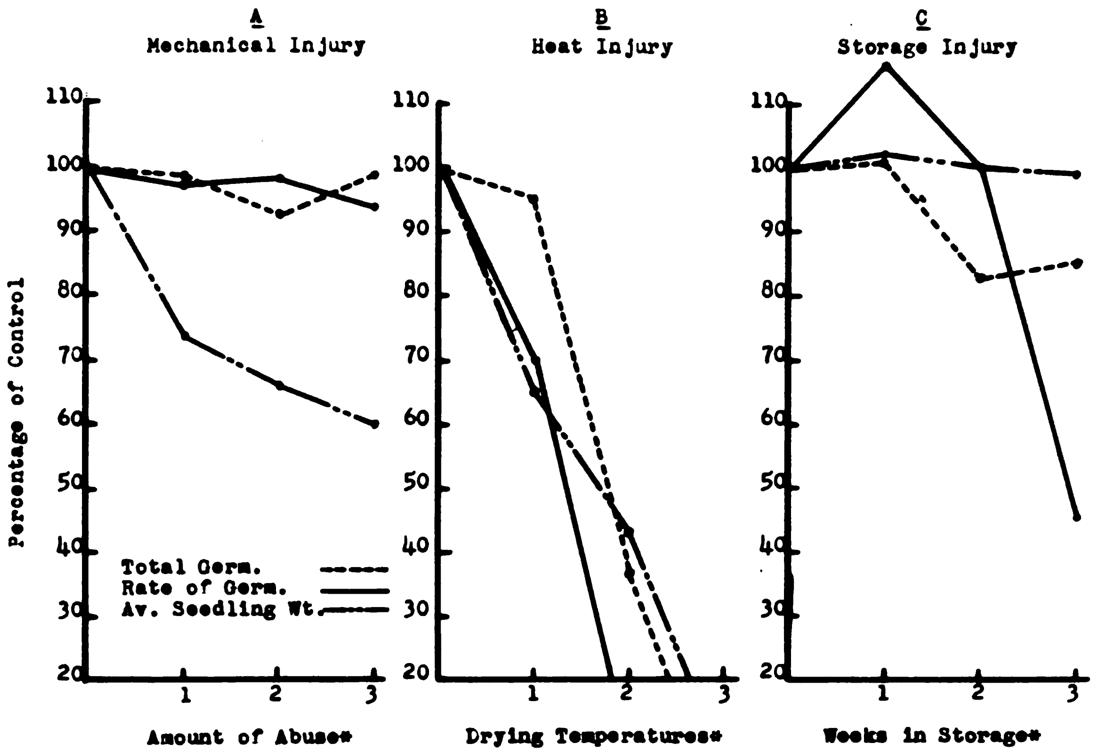


Figure 9. Corn - A comparison of the effects of injury on total germination, rate of germination, and average seedling weight.

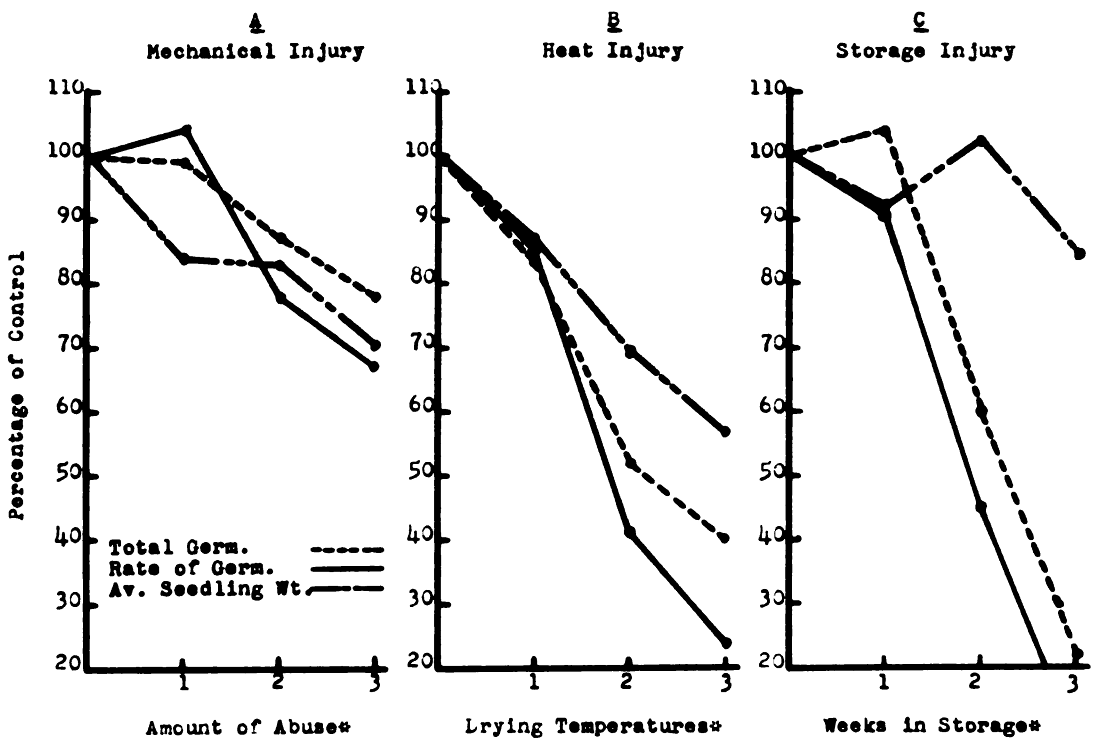
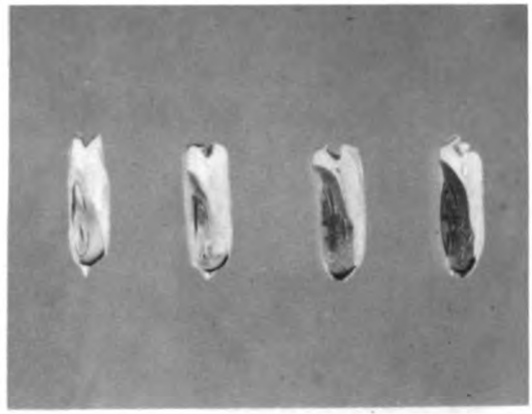


Figure 10. Wheat - A comparison of the effects of injury on total germination, rate of germination, and average seedling weight.

*See opposite page for details

1. 2. 3. 4. 5.

A.

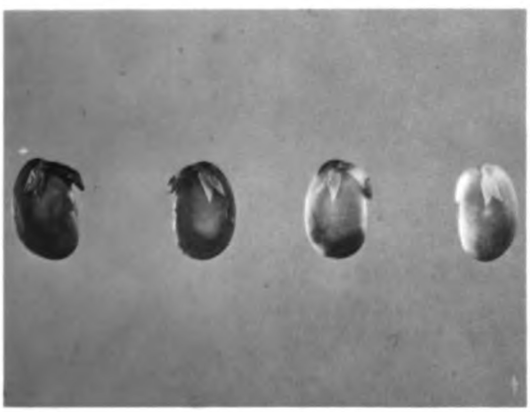


B.

1. Stored at 86% R.H. 19 wks.
2. Beaten x 4F-stored 4 mths.
3. Freshly beaten x 4F
4. Dried at 55°C
5. Control

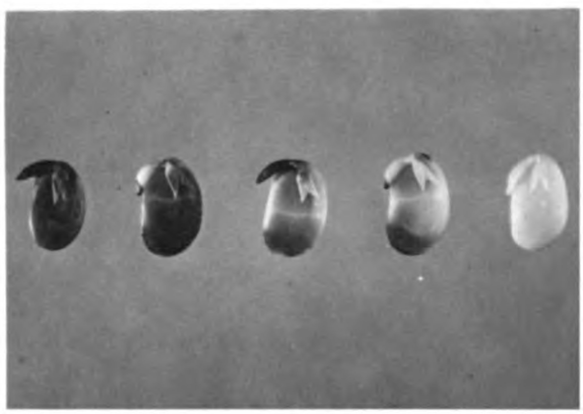
Range in coloration of seeds stored at 86% R.H. for 19 weeks

Figure 11. Tetrazolium test on corn seeds injured in various ways



1. 2. 3. 4.

A.

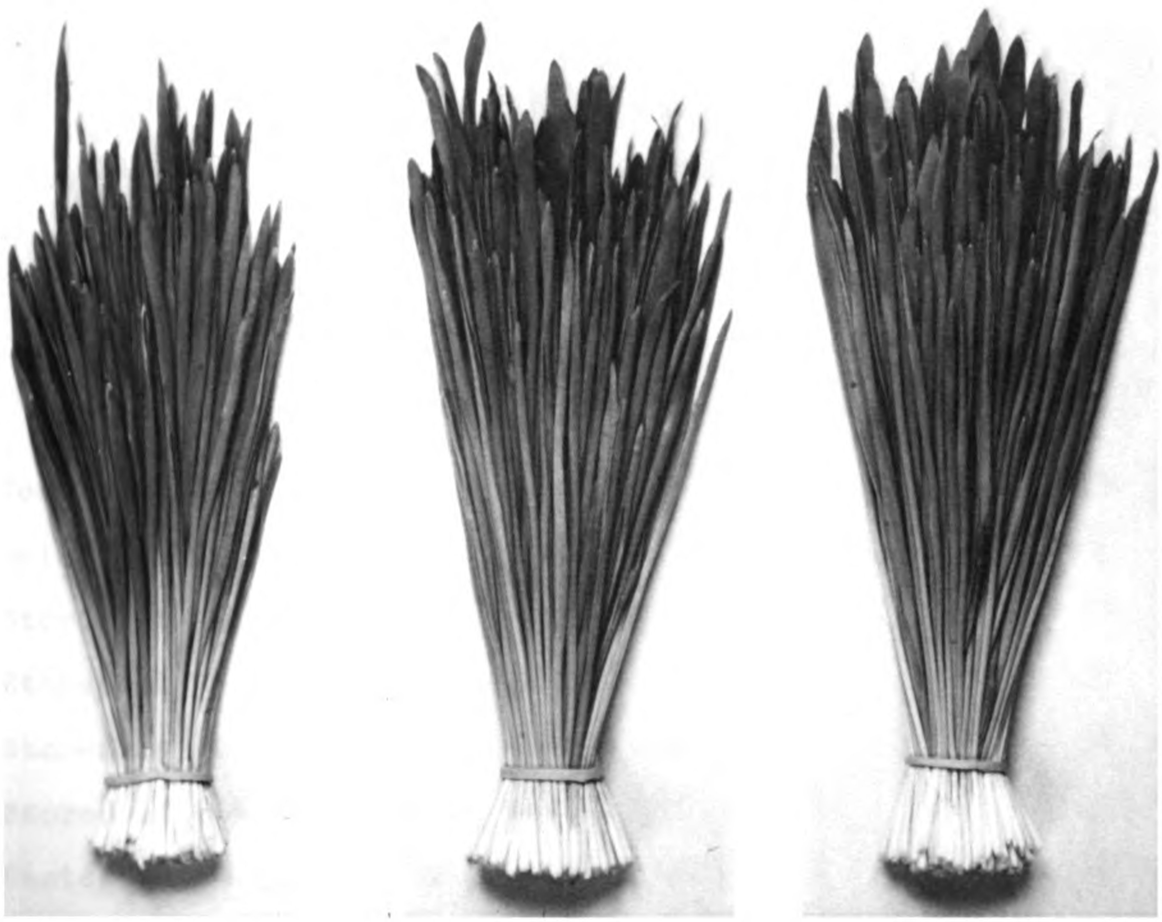


B.

1. Control
2. Stored at 86% R.H. 7 wks.
3. Stored at 86% R.H.15 wks.
4. Stored at 86% R.H.19 wks.

Range in coloration of seeds stored at 86% R.H. for 15 weeks

Figure 12. Tetrazolium test on bean seeds stored for different lengths of time at 86 per cent R.H.



1. 2. 3.

1. Stored at 86% R.H. 19 weeks
2. Control
3. Stored at 75% R.H. 19 weeks

Figure 13. The effects of storage at high relative humidities on barley seedlings

TABLE II

THE EFFECTS OF INJURY ON TOTAL GERMINATION, RATE OF GERMINATION, AVERAGE SEEDLING WEIGHTS, AND TETRAZOLIUM TEST RATINGS. THE MEASUREMENTS ARE GIVEN AS PERCENTAGES OF THE CONTROL

A. CORN

	Germination Total	Germination Rate	Average Seedling Weight	Tetrazolium Test
Control	100	100	100	100
Dried at 60°C	101	28	84	84
Stored at 75% R.H. for 15 wks.	100	100	93	97
Stored at 75% R.H. for 19 wks.	100	115	93	55
Stored at 86% R.F. for 15 wks.	83	36	100	68
Stored at 86% R.H. for 19 wks.	85	26	99	52
Beaten x 8F	99	94	60	52

B. BEANS

	Germination Total	Germination Rate	Average Seedling Weight	Tetrazolium Test
Control	100	100	100	100
Beaten x 2F	17	5	59	97
Stored at 75% R.H. for 19 wks.	104	98	97	83
Stored at 86% R.H. for 19 wks.	0	0	0	27

DISCUSSION

The purpose of this investigation was to examine the relationships between the total percentage germination and the other characteristics relating to germination in seeds that may have suffered some type of injury. To simplify the discussion, the nature of each test may be listed briefly as follows:

I. Total percentage germination or number of seedlings.

II. Rate or relative rapidity of germination.

III. Vigor or size of seedlings as indicated by weight.

IV. Vigor as indicated by tetrazolium tests.

The total germination or the maximum number of seedlings from a treated sample was compared to that of the control. For example, if the control gave 90 per cent total germination and the treated sample gave 60 per cent, the ratio of 60 to 90 or 67 per cent was considered the germination value of the sample.

The rate or rapidity of germination has been taken as the relative number of seedlings found when one half of the control sample had germinated. For example, if the curve of daily germination showed that one half of the seedlings (90/2) in the control had been produced by the end of 3 days, the count from the treated lot at the end of 3 days was taken and compared with the 45 seedlings of the control. If this number were 15, then the ratio of 15 to 45, or 33 per cent would be considered the rate or rapidity of germination of the sample.

The vigor or size of seedlings was obtained by dividing the total weight of the seedlings from a given treatment by the number of seedlings from that treatment. The average seedling weight for the treatment was then expressed as a percentage of that of the control.

Seeds that were subjected to the tetrazolium test (See page 17) were given a rating of 1 to 4 according to the intensity and pattern of staining. The sum of the ratings for each sample was compared with that of the control.

To make comparisons more meaningful, the measurements for each test have been presented as percentages of the controls in Table II, page 45; Figures 1 and 2, page 31; 5 and 6, page 38; and 7 to 10, pages 40, 42.

Mechanical Injury - Mechanically beating barley had practically no detrimental effect on the total germination, the rate of germination, or the average seedling weight in spite of very extensive abrasions. (See Figure 7A, page 40.) It appears that the palea and lemma protected the seed from injury, and that the extensive damage to the palea and lemma reduced mechanical resistance to germination. Toole *et al* (33) found that the germination of seeds of many grasses, including barley, was improved by cutting, breaking, acidtreating, or removing certain seed coverings. The tetrazolium tests did not indicate any injury to the barley seeds.

Bean seeds were found to be very susceptible to mechanical injury, particularly in dry samples. In general, total germination and the rate of germination fell off at about the same rate. The average seedling weight was reduced considerably, but not to the same extent as the rate and total germination. (See Figure 8A, page 40.) The tetrazolium test was of no value in determining either the site or extent of the injury caused by mechanically beating bean seeds.

The response of corn and wheat to mechanical injury was very different from that of barley or beans. (See Figure 9A and 10A, page 42.) The total germination and the rate of germination were only slightly reduced whereas the average weight of the seedlings was reduced considerably. The increased activity of pathogens on the injured seed was probably partly responsible for the reduction in weight of the seedlings. However, even when a suitable fungicide was used, the differences were significant. This is in agreement with results obtained by Funk (19) with treated corn seed.

The tetrazolium test on mechanically injured corn and wheat did not indicate the site of injury and differed from the control only in the intensity of the red coloration. It did appear, however, to give a fairly accurate indication of the vigor of the seedlings as measured by the average seedling weight. (See Table II, page 45, and Figure 11A, page 43)

Heat Injury - The average seedling weight of barley which had been dried at high temperatures showed a more rapid decline than either the total germination or the rate of germination. (See Figure 7B, page 40.) Corn showed an almost simultaneous decline in all three measurements. (See Figure 9B, page 42.)

The tetrazolium test on heat-injured corn gave results which showed a close correlation with the average seedling weight. (See Table II, page 45.) It is felt, however, that additional work should be done in this area in order to verify the existence of a close correlation between these two measurements.

It was possible to distinguish between storage injury and heat injury in both corn and wheat by the tetrazolium test. Heat-injured seeds showed a uniform light coloration while storage-injured seeds showed variability in intensity and pattern of coloration. Mechanical injury also gave a uniform light coloration and therefore could not be distinguished from heat injury. (See Figure 11A, page 43.)

Storage Injury - The results from these experiments indicate that storage at high relative humidities for a limited period improved the total germination, the rate of germination, and the average seedling weight. The partial hydration of the seeds apparently stimulated enzyme activity, (Mayer & Anderson, 24) and although this activity was halted again when the seeds were placed in dry storage, they seemed to have been left in a state of "preparedness". When these seeds were placed under conditions which were favorable for germination, they were apparently not only able to germinate more rapidly, but were also able to utilize their reserve food supply more efficiently and produce larger seedlings.

Continued storage at high relative humidities beyond this period of "stimulation" resulted in a rapid decline in the rate of germination of seeds of barley, beans, corn, and wheat. The total germination of barley, beans, and wheat declined almost as rapidly as the rate of germination. (See Figures 7C and 8B, page 40, and 10C, page 42.) The total germination of corn did not decline as rapidly as did the rate of germination. (See Figure 9C, page 42.)

The average seedling weight for barley, corn, and wheat was reduced only slightly by storage for as long as 19 weeks at 86 per cent relative humidity. (Figure 6A, page 38.) The average seedling weight of beans declined almost as rapidly as the total germination. It seems, therefore, that the effects of prolonged storage at a high relative humidity can be detected first by its effect on the total germination and the rate of germination. (See Figures 7-10, pages 40, 42.)

When the tetrazolium test was applied to seeds that had been stored at high relative humidities, it was found that they showed a wide range in coloration and staining patterns. This was especially noticeable with the beans. (See Figures 11B and 12B, page 43.) Some seeds stained a bright red and could not be distinguished from the controls, whereas others failed to stain at all. Between these extremes there were some showing definite dead areas. Some samples which still contained some seeds that appeared equal to the controls were shown by a germination test to have zero germination. This suggests that the process of deterioration had probably already begun in the seeds which appeared to be equal to the controls. It also suggests that once this process of deterioration sets in, it proceeds rapidly to the death of the individual seed. This idea was suggested previously by Barton (1). Where storage damage was less severe the germination test showed that the seeds were actually of a higher quality than the tetrazolium test indicated. (See Table II, page 45.)

The more rapid decline in total germination than in average seedling weight could be explained by the fact that seeds within a given sample do not all begin this process of deterioration at the same time, and until they do begin to deteriorate, their vigor probably remains approximately equal to that of the controls. Thus, early death of weak seeds improved the average vigor of the survivors.

In the case of corn, the tetrazolium test consistently indicated that the quality of the seed was lower than the germination tests showed it to be. (See Table II, page 45.) These results are not in accordance with those of Rice (29) who found that the tetrazolium test was effective in evaluating the vigor of naturally aged corn seed after unfavorable storage.

From this study it is apparent that seeds vary widely in their response to different types of injury. The results also show that no one measurement gave a complete and accurate indication of the quality of the seed or its agricultural value.

Although no general and invariable correlation was found between the total germination, the rate of germination, the average seedling weight, and the tetrazolium test, it seems that injury may be indicated by its effect on one or more of these measurements.

The total germination, rate of germination, and seedling weight are all closely related to the agricultural value of seeds. A decline in one or more of these characteristics is undesirable, and indicates that the process of deterioration has begun. It is possible to have a relatively high total germination and have seedlings that lack vigor, as was the case with mechanically injured corn and wheat. (See Figure 1, page 31.) It is possible, also, to have a low total germination and have seedlings with excellent vigor as was the case with storage-injured barley, corn, and wheat. (See Figure 6, page 38.) On the other hand, total germination, rate of germination, and average seedling weight all fell off rapidly with heat injury in barley, corn, and wheat. (See Figures 7B, page 40, and 9B and 10B, page 42.) Beans also responded in this way with mechanical and storage injury. (See Figure 8A and B, page 40.)

When the total germination is reduced before the average seedling weight, it would be possible to compensate for this with the use of a percentage germination test by increasing the rate of seeding. Such compensation would not be possible, however, when the average seedling size is reduced before the total germination.

In evaluating the quality of seed, it would be helpful to know which characteristic or measurement was affected first by injury. The results obtained in this study suggest that it might be possible to ascertain whether total germination, rate of germination, or seedling weight is reduced first in a given type of seed. For example, in injured barley the rate of germination was reduced first and/or most rapidly for all three types of injury. With injured beans the total germination was reduced first. In general, the seedling weight was reduced first in injured corn, and the rate of germination first in injured wheat. Thus, in general, poor or injured seed is first recognized in barley and wheat by <u>slow</u> germination; in beans by <u>low</u> <u>percentage</u> <u>germination</u>; and in corn by <u>small</u> <u>seeding</u> <u>size</u>. Various exceptions will be seen in Figures 7 to 10 on pages 40 and 42.)

It is suggested that a more accurate indication of the true "planting value" of seeds could be obtained if information regarding the characteristic or measurement affected first by injury in a given type of seed were considered in addition to the standard germination test.

SUMMARY

In this study, barley, beans, corn, and wheat seeds, and to a limited extent, alfalfa seeds were used. Different seed samples were subjected to various amounts of mechanical abuse, different drying temperatures, or different lengths of time in storage at high relative humidities.

Germination tests on the "treated" samples and their controls were carried out chiefly in flats in the laboratory with a limited number being carried out in a germinator and in the field.

The total germination, rate of germination, and average seedling weight was determined for each sample. These measurements were then calculated as a percentage of the corresponding measurement of the control in order to make the comparisons more meaningful.

The tetrazolium test was used to a limited extent so that results from this test could be compared with the results obtained from the germination tests.

CONCLUSIONS

The following are the conclusions that have been drawn from this study;

1. The types of seeds differed widely in their response to abuse.

2. Various types of injury had different effects on a given type of seed.

3. No close correlation was found between any of the measurements used.

4. Total germination in many cases did not give an accurate indication of the quality of the seeds.

5. The average seedling weight appeared to be a good index to the vitality of mechanically injured seed.

6. The rate of germination in some cases gave a fairly accurate indication of the reduction in vitality.

7. The tetrazolium test gave evaluations of quality which varied considerably, both above and below those of the average seedling weight.

8. The characteristic or measurement that is known to be affected first in a given type of seed could be used as a measure of the quality of the seed.

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