TB 708 (1940) USDA TECHNICAL BULLETINS UPDATA
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NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 708 — April 1940

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

A STUDY OF RAPID DETERIORATION OF VEGETABLE SEEDS AND METHODS FOR ITS PREVENTION.[1]

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INTRODUCTION

It is common knowledge that most vegetable and many other farm-crop seeds rapidly decrease in viability when stored at high temperatures and high humidities. Rapid deterioration is an especially serious problem in warm coastal regions or on islands. In such a warm, humid region as the Gulf States the percentage of germination and vitality of certain seeds may decrease to a serious degree during the period between shipment of the fresh seed to the local dealer by the producer and the time of sowing by the farmer. This is especially true in the instances of large quantities delivered to a local dealer or a large planter at one time but intended for sowing over a period of weeks. Sometimes reduction in acreage or inability to plant all seed

[1] Submitted for publication May 16, 1939.

[2] The authors gratefully acknowledge the valuable assistance given during the course of these investigations by Allan R. Eberle, David L. Stoddard, and Robert Shosteck, scientific aides, who assisted with the laboratory and statistical work, and by Edgar Brown, head of the former Division of Seed Investigations, and W. A. Davidson, head of the enforcement of the Federal Seed Act, who generously made available a large share of the laboratory germination facilities required.

intended for one crop season results in surpluses that will be of little if any value if held in common storage until the next crop season.

There is an increasing appreciation of the losses that may occur during storage of vegetable seeds, and the use of cold storage is receiving consideration; but there is a lack of knowledge, among those most concerned, of the general principles involved in safe seed storage. Although there have been many experiments to show the longevity of different seeds, comparatively few have shown the rate of deterioration at known temperatures and humidities. However, Duvel (*8*),[3] Heinrich (*9*), Beattie and Boswell (*3*), Kearns and Toole (*12*), and Barton (*2*) have shown a close relationship between moisture content of seed and temperature of storage as factors in the deterioration of seeds. In general, if either humidity or temperature is high, the other must necessarily be low for safe storage of seeds. The comparative behavior of different species at a given storage condition has not been satisfactorily determined.

The work mentioned above has demonstrated the great importance of moisture content of seeds on retention of viability. Coleman and Fellows (*6*) and Humphries and Hurst (*11*) have studied the equilibrium moisture content of various seeds at measured atmospheric humidities, but further information, especially on other species, is needed as a guide to safe practices in handling seeds. How long is required for a given species of seed to absorb a harmful quantity of water at a stated humidity and temperature? And how long can the seed tolerate such a moisture content and temperature before definitely measurable harmful results become evident? Although seed has been unavoidably exposed for a short time to conditions resulting in a harmful moisture content, can that water be driven off safely and quickly at high temperature, preventing subsequent damage?

These questions are of some interest in regard to the maintenance of proper long-time storage conditions, but are of chief importance in connection with transportation—especially by water—and short-time storage incidental to merchandising operations and to holding seed on the farm. Suppose seed is shipped by boat to some point in the humid Tropics and develops an excessive moisture content before it can be delivered to the consignee, who will retail it or store part of it over a period of a few weeks before it is all planted. In the absence of cold storage, what can be done to prolong the vitality of such seed?

The present studies were undertaken to obtain accurate measures of the effects of factors already known to be important, singly and by interaction with one another.

The literature on longevity of seeds and the effect of storage conditions has been reviewed recently by Crocker (*7*) and so will not be extensively reviewed here. In the Discussion (p. 42), however, the results of a number of other investigators will be considered as they may be closely related to the present study.

The storage and dehydration work was done at the cold-storage laboratory of the Division of Fruit and Vegetable Crops and Diseases at the Arlington Experiment Farm, Arlington, Va.; the work on germination of seeds in soil was done at the Arlington Experiment Farm; the work on germination of the small seeds was done in Washington, D. C., and at the United States Horticultural Station, Beltsville, Md.

[3] Italic numbers in parentheses refer to Literature Cited, p. 46.

MATERIALS AND METHODS

SEEDS

Seeds of the 1937 crop of Henderson bush lima bean, Bountiful bush snap bean, Narrow Grain Evergreen sweet corn, Detroit Dark Red beet, All-Seasons cabbage, Chantenay carrot, Yellow Bermuda onion, Long Standing Bloomsdale spinach, and Bonny Best tomato were obtained from reliable commercial sources. Spanish 18–38 peanut was obtained from an experimental stock of the Division of Fruit and Vegetable Crops and Diseases. Immediately upon delivery the seeds were placed in cold storage at 40° F. and a relative humidity of 40 to 50 percent. Seeds of the different crops were received over a period of 2 weeks before all were on hand. They remained in storage a few more days before all equipment and material were in readiness for setting up the experimental conditions.

The peanuts were hand-shelled and hand-picked to avoid damage to the seeds.

Samples for moisture content and germination determinations were drawn on June 25, 1938, the day the seeds were placed under experimental conditions, and the germination tests were started on June 27.

STORAGE CHAMBERS

Seven storage conditions were provided for each of the 10 kinds of seed. Six of the storage compartments consisted of closed sheet-iron chambers, approximately 3 by 3½ by 3½ feet, each equipped with a fan to maintain a gentle air movement throughout the chamber. Three of the chambers were located in each of two insulated rooms maintained close to 50° and 80° F. respectively by brine refrigeration coils, circulation fans, and thermostatically controlled electric strip heaters. The seventh storage chamber consisted of a cage 3 by 3½ by 3½ feet, covered with 20-mesh copper screen to exclude insects and rodents, and was located in a small frame warehouse without temperature or humidity control.

At each controlled temperature, one chamber was maintained at approximately 80-percent relative humidity, one at 65, and one at 40 to 50. Humidity was controlled by placing sufficient anhydrous calcium chloride with or without water in each chamber to maintain the required difference between wet- and dry-bulb thermometer readings. The thermometers inside the chambers were read twice daily through small glass windows, without opening the chambers. The desired relative humidity generally was maintained within ±3 percent. The chambers were opened only very briefly and at intervals of several days for the removal of samples or for adjusting the supply of calcium chloride and of water.

PREPARATION OF SEED LOTS

In setting up the study two series of seed lots or samples of each species were prepared and all lots of a series placed under the experimental conditions within an hour's time. Every sample to be drawn from the chambers over the entire study was accurately weighed and put in a separate container before being placed in the chamber. This was done in order to avoid, insofar as possible, the difficulties that would certainly be encountered in attempting to draw dependable small samples from large packages of seeds. No seed was disturbed in any way from the time of placement in the chamber until it was withdrawn for study. Every container of a given species was identical in size, exposure, and contents in all experimental conditions.

The first series of samples, hereinafter called the small samples, were accurately weighed into small, shallow, round metal boxes, known in the trade as ointment boxes. The diameter of container and nominal weight of seed for each species were as follows:

Lima and kidney beans, 3-inch box, 100 gm.
Sweet corn, 3-inch box, 75 gm.
Peanut, 3-inch box, 80 gm.
Beet and tomato, 2⅜-inch box, 10 gm.
Cabbage, carrot, onion, and spinach, 1⅞-inch box , 10 gm.

The 75- to 100-gm. samples were weighed to the nearest 5 mg. on a high-grade torsion balance, and the 10-gm. samples to the nearest 0.5 mg. on an analytical balance.

The boxes of seeds were uniformly spaced on wooden strips and left open to the air in the chambers. They were secured against spilling by setting the boxes into the inverted lids, which were tacked to the wooden strip. Eleven strips, each carrying one box of each of the 10 species, were placed on rabbeted guide strips in each chamber, with free air circulation around each of them.

The second series of samples consisted of much larger quantities of accurately weighed seed in muslin bags in duplicate, placed upon a four-mesh screen shelf below the small samples, in each chamber. The weight of seed of each species to the nearest 0.1 gm. in each bag was:

Lima bean, kidney bean, sweet corn, 2,000 gm.
Peanut, 1,200 gm.
Carrot, 1,000 gm.
Beet, onion, spinach, 750 gm.
Cabbage, 700 gm.
Tomato, 400 gm.

The large number of small samples described was designed to permit withdrawal of samples at 10-day intervals for determination of absolute weight, moisture percentage, and germination percentage. The large samples in bags were provided for studies of rapid dehydration, if and when dangerously high moisture contents were developed.

ROUTINE FOR SMALL SAMPLES

Beginning July 5 and at 10-day intervals thereafter except as noted, a series of 11 samples, each sampling including all species, was drawn from each of the 7 treatments. The boxes were closed at once upon removal from the chambers. The low-temperature samples were placed in a tightly covered vessel before removal to room temperature and were set aside to be handled last during the day's work, to permit them to attain room temperature before exposure to air with a dew point above the temperature of the seeds and containers.

Upon opening each box the contents were promptly weighed in a tared vessel to the same degree of accuracy above mentioned. The sample was mixed and a portion accurately weighed into a shallow-form glass-stoppered weighing bottle of about 10 gm. for beans, sweet corn, and peanuts, and 2 gm. for the other seeds. Sufficient seed was then removed from each sample for duplicate germination tests of 100 seeds each of beans, sweet corn, peanuts, spinach, and beets, and for quadruplicate 100-seed tests of the remaining four species. The residue of the lot removed from the chamber was then weighed to the nearest 0.5 mg., returned to its box, and closed for storage at 32° F. and later observations.

The samples for moisture were dried in a large forced-circulation electric drying oven at 100°±0.5° C. for 24 hours, stoppered, cooled over calcium chloride, and weighed.

The portions drawn for germination tests were placed under germination conditions on the day following removal from the chambers. The above routine was adhered to rigidly throughout the study, so the results are on a comparable basis.

GERMINATION TESTS

IN GREENHOUSE

Seeds of lima bean, kidney bean, sweet corn, and peanut were germinated in sterilized soil in a greenhouse that was shaded with whitewash strips on the roof from July until October. The seeds were sown in flats approximately 12 by 16 by 2½ inches, containing 2 inches of friable sandy loam greenhouse soil, and were coverd with one-fourth inch of clean sand. Soil and sand had been sterilized at 70° to 75° C. to kill weed seeds and most fungi. Before covering, the seeds were lightly pressed into the moist soil surface incidental to counting and placing with a vacuum seed counter as described by Brown, Toole, and Goss (*5*). Tests of 100 seeds per flat were in duplicate unless otherwise stated.

Germination counts were made after 1 to 2 weeks, depending upon the species and the weather. Generally three classifications of seedlings were attempted, namely, (1) normal, (2) mechanically injured or obviously genetically abnormal seedlings, (3) other weak seedlings of doubtful field-survival value. In this study the percentages of normal and of weak but mechanically uninjured seedlings are of most interest, since the mechanical injuries—such as "snakehead" or broken plumules in beans—and genetic abnormalities remained nearly a constant percentage of the total number germinating, throughout the study.

IN LABORATORY

The beet, cabbage, carrot, onion, spinach, and tomato seeds were germinated between blotting paper pads, generally in quadruplicate 100-seed tests in accordance with the best laboratory procedure developed by seed analysts, and as recommended by the Association of Official Seed Analysts of North America (*1*, *table 3*). In the laboratory germination tests, only those seeds were considered as germinated which produced normal seedlings capable of continued development under favorable conditions. A record was made of the abnormal growths not considered as germinated.

DRYING EQUIPMENT

At intervals, some time after the seeds in bags in certain chambers had developed what would appear to be a dangerously high moisture content, one bag of each species was taken from a specific chamber for quick dehydration to a safe moisture content.

Drying was effected in two identically built "tunnels," 2 by 2 by 10 feet inside, made of wood and insulating board. The top was hinged to be opened for easily placing in or removing seed at any time at any position in the compartment. A common 16-inch office-type electric fan forced air into each tunnel through a cylinder of galvanized sheet iron 14 inches in diameter and 2 feet long, containing well-distributed coils of No. 19 nichrome heater wire. The outlet end of the tunnel was equipped with a sliding panel of insulating board that could be wedged in any position, varying the size of the outlet to control rate of air flow.

The heater for the tunnel to be run at "high" temperature consumed about 5,500 watts and the other about 4,500 watts of electric current. The outlet air temperature of the "high" tunnel was generally about 63.5° C. (146° F.) and of the "low" tunnel 48.5° C. (119° F.). The higher temperature could be maintained only by nearly closing the outlet of the tunnel, reducing the air flow to but 40 cubic feet per minute. This amounted to a complete change of air in the tunnel each minute. The low-temperature tunnel carried 275 cubic feet per minute, or an air change approximately every 9 seconds. The rate of air movement at the surface of the seeds spread on trays in the tunnel was, of course, higher than indicated by the total air movement through the system, but was not measured.

The air-flow determinations were made by W. P. Green and C. J. Thompson by means of a thermocouple anemometer designed in this Department by Hukill (*10*).

Within each tunnel two tiers of five trays each, one above the other approximately 10 and 18 inches above the floor, rested upon rabbeted guide strips attached to the vertical walls. The trays were approximately 18 by 24 by 1½ inches, with rims of wood and bottoms of 20-mesh copper screen. The air stream from the heater was directed slightly upward against the nearest trays, which were about 3 feet from the heater.

The temperature generally shown by a thermometer lying on the surface of the seed in the trays was 57° to 60° C. when the outlet air was 63.5°. The evaporation of moisture from the seed surface produced a marked cooling effect, but this diminished as the seed approached dryness. Temperatures of the seed interiors were not determined.

DRYING ROUTINE

Data from the small samples in the metal boxes served as a rough indication of the probable moisture content of the corresponding large samples in bags, and it was assumed that the latter would be slower in reaching a certain moisture level than were the small, fully exposed lots. The time of sampling was, therefore, largely arbitrary.

One bag of each species from a single humidity chamber, 10 in all, was quickly removed, and the entire contents of the bag were quickly weighed to the nearest 0.1 gm. Quantitative precautions were observed, and handling was as rapid as possible, to guard against error from loss of moisture from the seed. The seed was thoroughly mixed, and samples were drawn for moisture determination and duplicate lots for germination tests. The remaining seed of each bag was then divided into two approximately equal portions weighed to the nearest

0.1 gm., and each portion was spread on a tray for the drier, one to be dried at "low" and the other at "high" temperature.

From the gain in weight of the seed while in the chamber, and the weight of seed placed on each tray in each drier, quick calculation was made to determine approximately the weight to be attained by the lots in the drier upon the loss of the undesirable increment of moisture. The seed was removed at intervals and weighed to determine the progress of drying.

Upon termination of drying, the seed was weighed, samples were taken for moisture determination, and duplicate lots were withdrawn for quadruplicate germination test. The remaining seed from each tray was then weighed, placed in a muslin bag, labeled, and returned to the humidity chamber from which it had been taken earlier in the day.

In preceding paragraphs reference was made to drawing duplicate samples for quadruplicate germination tests. One each of these was for germination at once, the other for storing at 32° F. for later observation. Those to be stored at 32° were accurately weighed before being placed in storage.

TREATMENT OF DATA

Moisture content is expressed as percentage of fresh weight at the time of sampling.

Germination figures summarized in various tables are in all cases mean values, usually based on two to eight replications. Values for error and tests of significance of differences have been calculated by the analysis of variance method as adapted by Snedecor (*13*).

ENVIRONMENTAL AND PHYSICAL DATA ON SEEDS

EXPERIMENTAL CONDITIONS

Before presenting the data on effects of the experimental conditions upon moisture content and viability of seed, the accuracy of the control of the conditions should be critically examined. The extent to which it is possible to evaluate the results supposedly due to temperature, to humidity, and to interactions between them depends on how successfully the comparable temperatures and humidities were established and maintained.

Special consideration will be devoted to the three humidity chambers at each of the two controlled temperatures in efforts to evaluate the interaction of temperature and humidity in relation to seed-moisture content and viability. The results from the warehouse storage are important and will be described later but are not adapted to the study of interaction effects.

Figure 1 shows satisfactory temperature control but rather discouraging differences and fluctuations in humidities intended to be maintained at uniform comparable levels. Tables 1 and 2 show the 10-day mean temperatures and humidities, respectively, for the several storage conditions. The importance of the divergencies of temperature and humidity from the intended levels is emphasized in table 3, which shows the analysis of variance of the data for the three humidities and two controlled temperatures in tables 1 and 2.

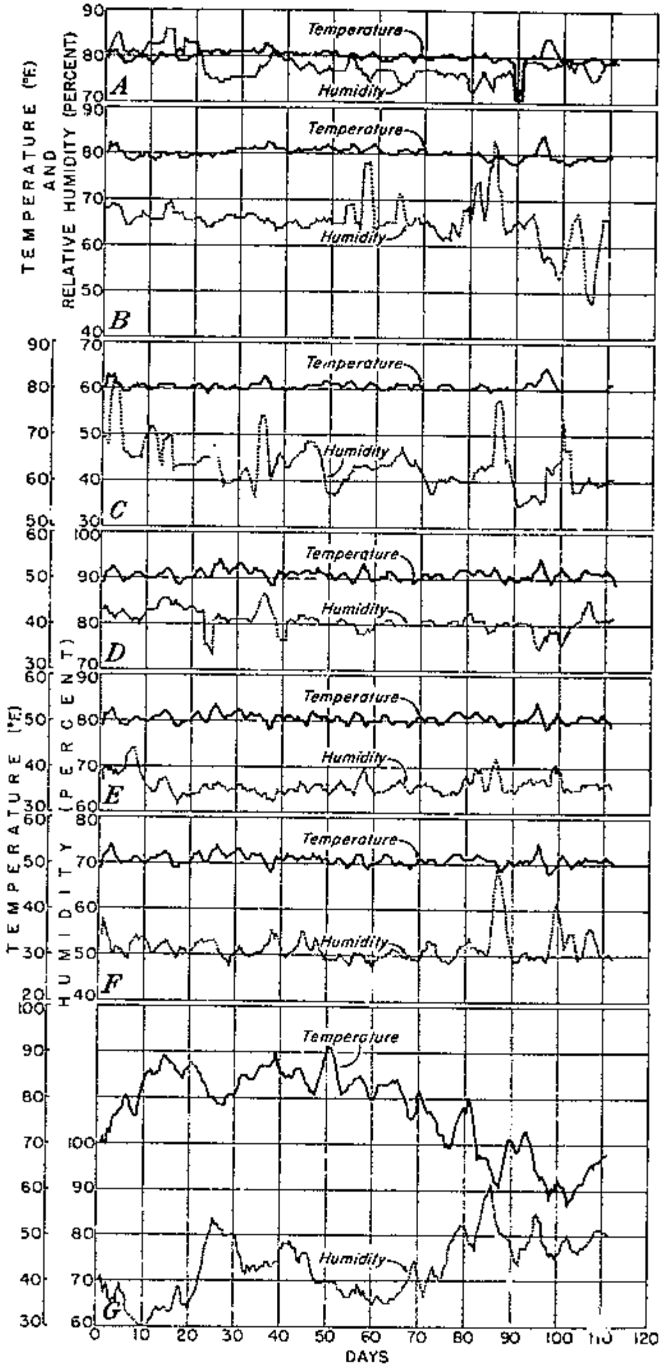

FIGURE 1.—Two-day moving average temperatures and humidities in the following seed-storage chambers: *A*, High humidity, 80° F.; *B*, medium humidity, 80°; *C*, low humidity, 80°; *D*, high humidity, 50°; *E*, medium humidity, 50°; *F*, low humidity, 50°; *G*, warehouse.

TABLE 1.—*Means of temperature for successive 10-day intervals for 7 storage conditions*

Days	Mean temperature for storage condition shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
10	79.4	79.6	80.0	50.5	50.2	50.8	76.0	66.7
20	79.8	79.6	80.6	50.3	50.5	50.7	85.2	68.1
30	80.9	79.8	80.3	51.8	51.5	52.0	83.0	68.5
40	81.0	80.1	80.6	50.9	50.6	50.9	84.3	69.3
50	80.6	80.2	80.8	51.1	50.6	51.1	84.9	68.5
60	80.0	80.0	80.7	50.6	50.4	50.5	85.4	68.2
70	79.8	70.5	80.5	50.3	50.2	50.4	82.0	67.5
80	79.6	79.2	80.3	50.9	50.8	51.0	74.8	66.7
90	78.0	79.2	80.2	50.9	50.6	50.6	70.3	65.7
110	80.2	79.6	80.9	51.2	50.8	50.9	61.6	65.5
251	80.5	78.8	80.4	50.7	49.9	50.0	45.3	62.2
Mean [1]	79.9	79.7	80.6	50.8	50.6	50.0	79.0	67.4

[1] Means for first 110 days only.

TABLE 2.—*Means of relative humidities for successive 10-day intervals for 7 storage conditions*

Storage period ending (days)	Mean humidity for storage condition shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10	82.1	68.4	50.0	81.8	69.5	52.2	66.2	66.9
20	83.3	66.6	46.1	84.0	64.7	51.0	62.8	65.5
30	75.4	65.5	43.3	79.1	65.4	51.4	73.4	64.8
40	78.5	65.9	44.5	81.4	64.2	51.2	74.6	65.8
50	77.4	65.9	45.0	80.8	65.2	51.5	75.1	65.8
60	77.2	69.0	42.6	79.6	66.0	49.2	68.4	64.6
70	76.2	67.0	44.4	80.4	65.4	49.6	66.3	64.2
80	75.7	67.0	40.9	80.9	65.6	51.0	72.5	64.8
90	75.0	70.3	44.3	80.2	67.0	55.0	82.7	67.8
110	78.2	60.3	40.1	79.8	66.6	52.8	78.0	65.1
251	79.2	66.3	39.6	80.9	67.0	50.8	73.2	65.3
Mean [1]	77.9	66.4	44.1	80.8	66.0	51.5	72.0	65.5

[1] Means for the first 110 days only.

TABLE 3.—*Analysis of variance of data on means of temperatures and humidities entering into tables 1 and 2* [1]

Source of variation	Degrees of freedom	Variance for—		Source of variation	Degrees of freedom	Variance for—	
		Temperature	Humidity			Temperature	Humidity
		V	V			V	V
Total	59	218.064	179.957	Dates × temperature	9	0.360	4.214
Between temperature	1	12,848.067	161.375	Temperature × humidity	2	.580	76.592
Between humidity	2	1.638	5,020.415	Dates × humidity	18	.091	4.303
Between dates	9	.700	9.635	Remainder (error)	18	.115	3.334

[1] Based on data for first 110 days only. Data for warehouse omitted.

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In table 3 it will be noted that discrepancy in temperature control was very small indeed, except between humidities. This discrepancy occurred almost entirely in the low-humidity chamber at 80° F. and was a result of inadequate air circulation in the room. It did not occur in the 50° room, where all chambers were on the same level.

Variances for humidity show large and highly significant differences between chambers at different temperatures that were intended to be maintained at equal relative humidities. This unfortunate lack of adequate control of the two "highs" and two "lows" prevents the most accurate evaluation of temperature effects upon viability for either humidity, but on the other hand gives a great deal of information on seed moisture in response to air humidity. Only the medium-humidity chambers were maintained at nearly equal levels. The standard errors for temperature and humidity control, based on interaction variance for temperature × humidity, were ±0.76° F. and ±8.8 percent relative humidity, respectively. In making comparisons of responses between temperatures, the possible influence of humidity differences must be kept in mind.

EFFECTS OF STORAGE CONDITIONS ON SEED MOISTURE

The first noticeable response of the seeds to a change or difference in storage condition is in their moisture content. Table 4 shows that under the conditions of these studies the changes in moisture content of seeds at 80° F. quickly reflect changes in humidity of their environment, even small fluctuation in 10-day means being reflected in per-

TABLE 4.—*Moisture content of seeds at high and low humidity at 80° F.*

AT HIGH HUMIDITY

Time in storage (days)	10-day mean humidity	Moisture in percentage of fresh weight of seed of—									
		Lima bean	Kidney bean	Sweet corn	Peanut	Beet	Cabbage	Carrot	Onion	Spinach	Tomato
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	......	11.1	11.6	12.0	6.1	10.1	7.6	9.1	10.1	11.4	9.2
10	82.1	14.1	15.9	13.8	......	17.3	11.7	15.1	14.8	15.5	12.4
20	83.3	17.1	18.3	15.4	10.3	18.5	13.0	16.4	15.9	16.3	13.2
30	75.4	16.2	16.1	13.1	......	14.8	10.2	12.6	13.3	14.3	11.2
40	78.5	17.1	16.9	13.5	8.5	15.5	10.7	13.5	13.9	14.8	11.6
50	77.4	15.7	15.2	12.5	......	14.1	9.4	11.7	12.5	13.9	10.9
60	77.2	15.5	14.6	12.3	7.7	14.4	9.4	11.6	12.6	14.1	10.6
70	76.2	15.3	14.9	12.5	......	14.3	9.6	11.8	12.8	14.2	11.1
80	75.7	14.0	13.1	11.4	6.6	12.0	8.1	10.1	11.0	12.7	9.9
90	75.0	14.8	14.0	12.0	......	14.2	9.3	11.5	12.4	13.7	10.8
110	78.2	15.7	15.3	12.4	7.9	13.7	9.5	11.6	12.5	13.8	10.6
Mean [1]	77.9	15.6	15.4	12.9	8.2	15.0	10.1	12.6	13.2	14.3	11.2

AT LOW HUMIDITY

Time in storage (days)	10-day mean humidity	Lima bean	Kidney bean	Sweet corn	Peanut	Beet	Cabbage	Carrot	Onion	Spinach	Tomato
10	50.0	9.8	8.6	8.3		7.5	5.7	6.9	8.0	9.3	7.3
20	46.1	9.1	8.0	7.8	4.5	7.6	5.7	6.6	7.7	8.8	7.0
30	43.3	8.5	7.5	7.2	......	7.4	...	6.8	7.7	8.7	7.1
40	44.5	8.3	7.3	7.3	4.2	7.3	5.5	6.7	7.6	8.6	7.1
50	45.0	11.2	7.5	7.1	..	7.0	5.2	6.3	7.3	5.1	6.7
60	42.6	8.5	7.3	7.3	4.5	7.6	5.7	6.9	8.0	9.0	7.3
70	44.4	8.6	7.5	9.6		6.9	5.3	6.4	7.5	8.4	6.9
80	40.9	8.0	6.9	6.9	4.1	7.0	5.3	6.3	7.3	8.3	6.6
90	44.3	8.0	6.9	6.7		6.8	5.0	6.1	7.0	7.9	6.4
110	40.1	7.8	6.5	6.6	4.0	6.9	5.1	6.1	7.0	8.0	6.5
Mean	44.1	8.5	7.4	7.5	4.3	7.2	5.4	6.5	7.5	8.5	6.9

[1] Excluding initial moisture content of seed.

centage moisture of the seed. At 50° (table 5) humidity was more nearly constant than at 80°, so less fluctuation in moisture content of seeds occurred.

TABLE 5.—*Moisture content of seeds at high and low humidity at 50° F.*

AT HIGH HUMIDITY

Time in storage (days)	10-day mean humidity	Moisture in percentage of fresh weight of seed of—									
		Lima bean	Kidney bean	Sweet corn	Peanut	Beet	Cabbage	Carrot	Onion	Spinach	Tomato
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	......	11.1	11.6	12.0	6.1	10.1	7.6	9.1	10.1	11.4	9.2
10	81.8	12.2	13.3	13.2	......	15.1	10.5	13.7	13.7	14.7	12.1
20	84.0	13.3	14.3	13.5	8.0	14.7	10.3	13.3	13.2	14.6	11.9
30	79.1	13.8	14.8	14.0	......	16.2	11.3	14.9	14.6	15.6	13.1
40	81.4	14.8	15.9	14.2	8.9	16.5	11.4	15.0	14.7	15.6	12.7
50	80.8	14.7	15.8	13.7	......	14.3	9.9	12.8	13.0	14.4	11.7
60	79.6	14.3	15.6	13.5	7.9	14.6	10.1	12.8	13.4	14.6	12.1
70	80.4	15.2	16.0	13.8	......	15.0	10.4	13.3	14.0	15.1	12.3
80	80.9	15.6	16.0	13.8	8.3	14.8	10.4	13.3	13.8	15.0	12.3
90	80.2	16.1	15.8	13.6	...	14.1	10.0	12.8	13.5	14.0	12.0
110	79.8	15.8	16.5	13.7	8.1	14.9	10.6	13.6	13.9	15.1	12.1
Mean [1]	80.8	14.6	15.4	13.7	8.3	15.0	10.5	13.0	13.8	15.0	12.2

AT LOW HUMIDITY

10	52.2	10.8	10.6	10.4	......	8.8	6.5	8.0	9.0	10.8	8.3
20	51.0	10.9	10.1	10.1	7.1	9.0	6.6	7.9	8.9	10.8	8.4
30	51.4	10.8	10.1	9.9	......	9.0	6.7	8.0	9.2	10.8	8.6
40	51.2	10.5	10.1	9.9	5.3	8.8	5.6	7.9	9.1	10.8	8.5
50	51.5	10.5	9.8	9.7	...	8.8	6.4	7.8	9.0	10.3	8.3
60	49.2	10.3	9.1	9.3	5.2	8.7	6.5	7.9	9.1	10.7	8.5
70	49.6	10.5	......	9.8	...	8.9	6.6	8.0	9.2	10.8	8.6
80	51.0	10.4	9.6	10.1	5.3	8.7	6.5	7.9	9.0	10.7	8.3
90	55.0	10.6	9.7	9.6	......	8.8	6.5	7.8	9.1	10.6	8.4
110	52.8	10.5	9.7	9.4	5.3	8.7	6.5	7.9	8.9	10.6	8.4
Mean	51.5	10.6	9.8	9.8	5.6	8.8	6.4	7.9	9.0	10.7	8.4

[1] Excluding initial moisture content of seed.

Table 5 shows that in a cool atmosphere (50° F.) at 80 percent humidity the moisture of most of the seeds had practically reached equilibrium in 10 to 20 days. Data in table 4 suggests that at 80° the increase in moisture content is more rapid than at 50°, but the high humidities at the two temperatures were nearly comparable for only the first 20 days, then at high temperature was sharply dropped.[4]

The mean moisture contents of the seeds at four storage conditions at 10-day intervals are shown in tables 4 and 5, while the means for the entire period for all conditions are shown in table 6. These figures indicate the relative moisture-absorbing capacity of different seeds at high humidities and the moisture-retaining capacity at low humidities. Bean, beet, and spinach are outstanding for the high moistures (14 to 15 percent) that they developed at high humidities, while onion, carrot, and sweet corn absorbed nearly as much (around 13 percent); cabbage reached 10+ percent, and tomato 11 to 12. Peanut absorbed very little water indeed, but, as will be shown later, was seriously damaged by that little. Analysis of variance of these data is shown in table 7.

[4] At this point a superficial mold appeared on sweet corn, beet, carrot, onion, and spinach. No molding occurred on seeds in bags. The humidity was dropped to avoid further mold development, and it fell lower than was intended.

TABLE 6.—*Moisture content of seeds held for 10 to 251 days under different storage conditions*

[Expressed as mean percentage of moisture calculated on fresh-weight basis]

Seed	Mean moisture content of seeds stored under conditions shown								Original moisture[1]
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean	
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lima bean	15.7	11.3	8.0	14.8	12.3	10.0	12.4	12.2	11.1
Kidney bean	15.5	10.7	7.3	15.5	11.0	9.9	11.0	11.8	11.6
Sweet corn	12.9	10.3	7.3	13.7	11.6	9.6	10.8	10.9	12.0
Peanut	8.2	5.6	4.2	8.3	6.3	5.5	6.4	6.3	6.1
Beet	14.0	9.9	7.1	15.1	10.5	8.8	11.0	11.0	10.1
Cabbage	10.0	7.3	5.3	10.5	7.9	6.4	8.0	7.9	7.6
Carrot	12.5	8.9	6.5	13.6	9.8	7.9	9.9	9.9	9.1
Onion	13.1	10.2	7.4	13.8	10.7	9.0	10.5	10.7	10.1
Spinach	14.3	11.2	8.4	15.0	12.0	10.6	12.0	11.9	11.4
Tomato	11.2	8.9	6.8	12.2	9.7	8.4	9.5	9.5	9.2
Mean	12.8	9.4	6.9	13.3	10.3	8.7	10.2	10.2	9.8

[1] Moisture content of seed at the beginning of the experiment.

TABLE 7.—*Analysis of variance of atmospheric humidity and of moisture content of 10 vegetable seeds stored at 3 humidity levels at 2 temperatures*

Source of variation	Degrees of freedom	Variance for air humidity and moisture content of seed[1]										
		Humidity	Lima bean	Kidney bean	Sweet corn	Peanut	Beet	Cabbage	Carrot	Onion	Spinach	Tomato
Total	59	179.98	6.12	9.06	4.68	2.52	9.60	3.81	6.95	5.67	5.09	3.37
Between storage periods	9	9.64	.27	.45	.71	.83	.79	1.14	.96	1.04	.36	.25
Between temperatures	1	161.38	4.99	21.96	32.80	3.33	8.07	3.60	18.96	11.01	21.72	18.28
Between humidities	2	5,020.42	147.33	1,046.84	1,078.82	28.08	258.25	87.73	175.50	136.24	128.94	83.74
Remainder (error)	47	6.99	1.25	1.05	.45	.46	.74	.76	.71	.89	.37	.23

[1] In no case is variance between dates significant, while in every case variance between temperature and between humidities is highly significant.

The relative resistance to water loss at low humidity will not be discussed in detail here because the humidities in question, 45 to 50 percent, were not excessive and showed no evident damage in any case.

The one comparison for the whole storage period that can indicate directly an interaction of temperature with humidity upon moisture content is that between the two medium humidities which show nearly identical means. It is notable that for every kind of seed at medium humidity, those at the higher temperature showed a slightly lower mean moisture content. This may appear in conflict with the fact pointed out above with reference to higher moisture content of seeds at 80° F. than at 50° at 80+ percent humidity. It should be recalled, however, that the former case involves but 20 days at high humidity, while the latter involves 110 days at a much lower level.

At a given relative humidity the seeds develop a slightly higher moisture content at 50° than at 80° F.

It is recognized that equal relative humidities at 50° and 80° F. mean vastly different absolute moisture conditions in the air. However, differences in vapor pressure, weight of water in the air, and vapor deficits afford no adequate explanation for differences in moisture content of seeds developed at different temperatures.

It is obvious from a glance at table 8, containing additional data on air conditions, and from consideration of the data in table 6, that relative humidity is much the best criterion of atmospheric moisture in estimating or judging how much increase there will be in the moisture content of seeds of known relative absorbing power. There are no evident interrelationships of physical characteristics of the air shown in table 8 that will aid in explaining the interaction of humidity and temperature upon seed-moisture content.

TABLE 8.—*Physical data on the prevailing atmospheric conditions in seven storage chambers* [1]

Condition and unit of measure	Conditions prevailing for chambers indicated						
	Temperature 80° F.			Temperature 50° F.			Warehouse
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent	
Temperature ° F.	79.9	79.7	80.6	50.8	50.6	50.9	79.0
Relative humidity percent	77.9	66.4	44.1	80.8	66.0	51.5	72.0
Dew point ° F.	72.5	68.0	57.5	46.0	39.5	34.5	70.0
Vapor present gr./lb.	120.0	103.0	70.5	48.0	36.0	29.0	110.0
Vapor deficit gr./lb.	35.0	51.0	87.5	9.0	10.0	26.0	40.0
Vapor pressure mm. Hg.	20.5	17.5	12.2	8.0	6.4	5.1	18.0
Vapor pressure deficit mm. Hg.	6.0	9.0	14.3	1.5	3.1	4.4	6.6

[1] All data except temperature and relative humidity are approximations read or calculated from a common psychrometric chart.

EFFECTS OF AIR HUMIDITY ON SEED MOISTURE

Table 9 presents a drastic condensation or summary of the data on effect of atmospheric humidity upon moisture content of the seeds studied for the first 110 days in this work. Each value in columns 2 to 6 of the table represents the mean of 10 moisture determinations from each storage chamber, except those for 66 percent humidity, which represent 10 from the 80° F. room plus 10 from the 50° room. The relative humidities indicated for columns 2 to 6 are the means of ten 10-day means for the respective chambers. The 66.2 percent heading is the mean of two chambers operated at 66.4 and 66.0 percent at 80° and 50° F. respectively. In developing the data in the remainder of the table, the seed-moisture figures for individual samples were utilized, together with the corresponding 10-day mean humidity values for each chamber (fig. 2). Tables 2 and 3 show the marked fluctuations in humidity that occurred in each chamber. Table 7 presents a summary of the analysis of variance in humidity and also in seed-moisture content of the seeds stored in the six controlled chambers, but it is less informative than table 9 because discrepancies in humidity control are confounded with temperature effects.

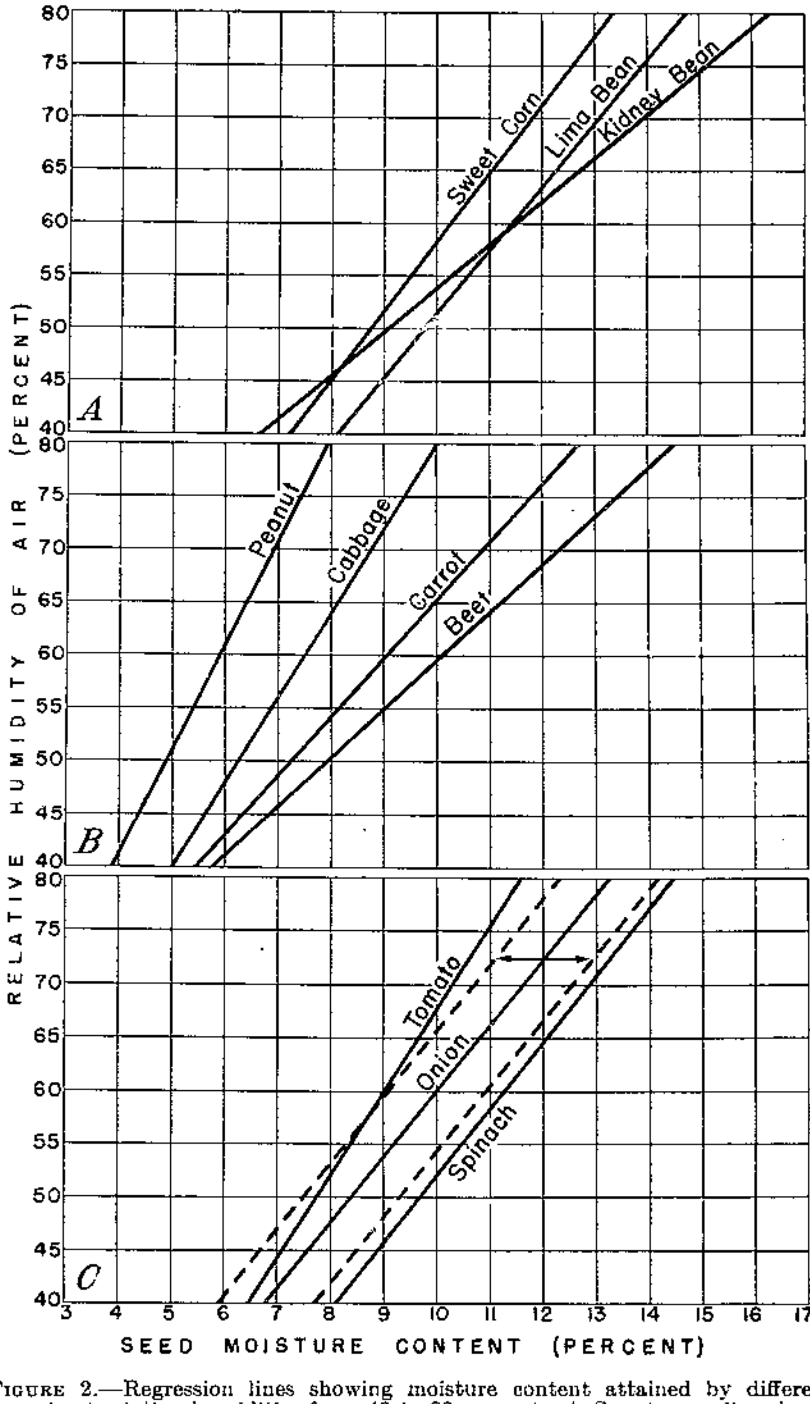

Figure 2.—Regression lines showing moisture content attained by different seeds at relative humidities from 40 to 80 percent: *A*, Sweet corn, lima bean, and kidney bean; *B*, peanut, cabbage, carrot, and beet; *C*, tomato, onion, and spinach. Dotted lines show error of estimate for onion.

TABLE 9.—*Summary of effects of atmospheric humidity upon moisture content of stored vegetable seeds*

Seed	Mean moisture content of seed stored at mean percent relative humidity and temperature shown [1]					Correlation between air-humidity and seed moisture		Coefficient of regression [4]		Error of estimate of covariance		Significance of temperature effect [5]
	80.8, L	77.9, H	66.2, L-H	51.5, L	44.1, H	Total [2]	Within temperatures [3]	Total	Within temperatures	Total	Within temperatures	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*r*	*r*	*b*	*b*	*s*	*s*	
Lima bean	14.6	15.6	11.8	10.6	8.8	0.893	0.913	0.165	0.165	1.12	1.06	Very high.
Kidney bean	15.4	15.4	11.3	10.0	7.4	.934	.943	.209	.207	1.09	.99	High.
Sweet corn	13.7	12.9	10.9	9.8	7.5	.932	.960	.150	.146	.79	.58	Very high.
Peanut	8.0	8.0	6.0	5.6	4.3	.886	.892	.099	.098	.75	.74	None.
Beet	15.1	15.0	10.2	8.8	7.2	.925	.926	.214	.214	1.19	1.20	Do.
Cabbage	10.5	10.1	7.6	6.4	5.9	.861	.865	.125	.127	1.00	1.00	Do.
Carrot	13.6	12.6	9.4	7.9	6.5	.926	.930	.182	.181	1.01	.98	Do.
Onion	13.8	13.2	10.5	9.1	7.5	.915	.914	.162	.161	.97	.97	Do.
Spinach	15.0	14.3	11.6	10.7	8.5	.945	.957	.150	.155	.71	.65	Very high.
Tomato	12.2	11.2	9.3	8.4	6.9	.938	.952	.128	.125	.61	.55	Do.

[1] Mean moisture content of seeds in percentage of fresh weight as removed from storage chambers at mean humidities and temperature shown. L=50° F.; H=80°.
[2] Degrees of freedom, 58.
[3] Degrees of freedom, 55.
[4] Change in percent moisture content of seed for each 1 percent air-humidity change.
[5] Based on variance due to temperature plus interaction between temperature and humidity, in comparison with remainder variance.

Despite a general lack of an over-all significant temperature effect, the remarkably consistent differences shown in columns 3 and 6 of table 6 (moisture content of seeds from 66-percent humidity at 80° and at 50° F.) suggest a definite effect of interaction between humidity and temperature upon absorption of moisture. The covariance between humidity and seed moisture was then calculated for the interaction "temperature × humidity" plus "temperature" (3 degrees of freedom) and for remainder (56 degrees of freedom). The results are shown in table 9. When "interaction" (temperature × humidity) is included as part of the influence exerted by temperature upon seed moisture in response to humidity, lima bean, kidney bean, sweet corn, spinach, and tomato all show significant effects. Even so, the regression and correlation coefficients calculated after removal of temperature effect are nearly identical with those calculated on the total sources of variation.

Although temperature appeared to have a definite effect on the moisture level developed in certain seeds at a given humidity, the rate of change with change in humidity appears to be practically the same at both these temperatures. Regression lines plotted from data for the two temperatures separately, therefore, are parallel or nearly so, even in those instances where temperature effect was highly significant.

The moisture contents for the 10 kinds of seeds adjusted to equal humidities are shown in table 10. It will be noted that although lima bean showed a significant difference in moisture response to humidity at the two temperatures, including interaction, there was no effect of temperature alone other than that associated with failure to keep humidities equal at the two temperatures.

TABLE 10.—*Adjusted mean moisture contents of seeds stored 10 to 110 days at different humidities at 80° and 50° F.*[1]

[See table 9]

Seed	Observed means		Adjusted means		Difference due to high temperature	Significance
	At high temperature	At low temperature	At high temperature	At low temperature		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	
Lima bean	11.89	12.46	12.16	12.19	−0.03	None.
Kidney bean	11.20	12.41	11.54	12.07	−.53	Low.
Sweet corn	10.23	11.71	10.47	11.47	−1.00	High.
Peanut	6.04	6.61	6.21	6.44	−.23	None.
Beet	10.70	11.43	11.05	11.08	−.03	Do.
Cabbage	7.77	8.26	7.98	8.05	−.07	Do.
Carrot	9.36	10.42	9.66	10.12	−.46	Low.
Onion	10.32	11.18	10.58	10.92	−.34	None.
Spinach	11.35	12.56	11.60	12.31	−.71	High.
Tomato	9.02	10.12	9.22	9.90	−.68	Do.

[1] Adjusted to equal humidities at the 2 temperatures.

There was no significant variance in humidity (of all chambers) or in seed-moisture content (seeds from all chambers) between dates of sampling of any species (table 7). Most of the total variation was contributed by differences between humidity levels (three at each temperature), but there was also a significant variance in humidity of chambers and moisture of seed, between temperatures. This last, however, was due largely to differences in humidity control at the two temperatures. The chamber run at 77.9 percent was intended to be run the same as the one at 80.8 percent, and the 44.1 and 51.5 percent were intended to be alike. The 66-percent chambers were controlled successfully. It should be determined, before placing too much dependence in the moisture-percentage data in table 9, how much effect temperature had on the moisture content of the seed in response to air humidity.

It is of special interest that from the adjusted mean moistures (table 10) kidney bean and carrot had about 0.5 percent, spinach and tomato about 0.7 percent, and sweet corn 1.0 percent higher moisture when stored at 50° than at 80° F. These differences are statistically significant, and in all cases storage at a low temperature resulted in higher mean moisture content than that developed at an equal humidity at a high temperature. The importance of these results lies in the potential danger of damage to seed with this higher moisture content when taken out of storage and exposed to high summer temperatures.

MOISTURE CHANGES IN SEEDS AT 32° F.

From the original studies of moisture equilibrium at the different storage conditions, information was available only at the two storage temperatures 80° and 50° F. Little information is available on the moisture attained by seeds in cold storage, therefore changes in weight were determined on the seeds removed from storage conditions at successive 10-day intervals and placed in storage at 32° at a relative humidity of approximately 60 percent where they remained for from 1 to 8 months. The final moisture content reached at 32° has been estimated from the changes in weight and have been grouped (table 11) as means of values from seeds previously stored at the two high humidities and at the five medium and low humidities in comparison with the mean initial moisture before the seeds were placed at 32°. The seeds transferred from high humidity all lost moisture, and the seeds from medium and low humidities gained in mean moisture while in cold storage. However, the final moisture contents of each kind of seed from the high humidities was significantly higher than those from the medium and low humidities. It may be that the period of storage was too short for final moisture equilibrium to be reached. The mean final moisture contents (last column of table 11) reached at 32° are in general agreement with the corresponding values of moisture content of seed stored at 66 percent relative humidity (columns 2 and 5, table 6). Although the results at 32° are estimates based on weight changes, the general indication is that the equilibrium moisture at 32° is of the same general order as that at 50° for the same humidity.

TABLE 11.—*Summary of estimated moisture contents attained at 32° F. and 60-percent relative humidity by seeds previously exposed to different humidity treatments*

Seed	Previous storage at—				Mean final moisture [5]	Seed	Previous storage at—				Mean final moisture
	High humidity (means of 22 determinations)[1]		Medium to low humidity (means of 55 determinations)[4]				High humidity (means of 22 determinations)[1]		Medium to low humidity (means of 55 determinations)[4]		
	Initial moisture[2]	Final moisture[3]	Initial moisture[2]	Final moisture[3]			Initial moisture[2]	Final moisture[3]	Initial moisture[2]	Final moisture[3]	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Sweet corn	13.3	11.9	10.0	10.8	11.4	Spinach	14.6	12.3	10.9	11.6	12.0
Beet	15.0	12.7	9.5	10.9	11.8	Tomato	11.7	9.8	8.7	9.4	9.6
Cabbage	10.3	8.4	7.1	8.0	8.2						
Carrot	13.1	10.0	8.6	9.4	9.7	Mean [5]	13.1	10.9	9.2	10.1	10.5
Onion	13.5	11.4	9.6	10.8	11.1						

[1] 11 lots from 78-percent humidity at 80° F. and 11 from 81 percent at 50°.
[2] Actual moisture determination on samples removed from treatment.
[3] Moisture content estimated from change in weight at 32° F.
[4] 11 lots from each of the following conditions: 66-percent humidity at 50° and 80°, 51-percent humidity at 50°, 44-percent humidity at 80°, and warehouse.
[5] Between single values for final moisture, differences as great as 0.3 percent are significant; between means, all differences are significant.

CHANGES IN SEED WEIGHT

It might appear that changes in total weight (expressed as percent of original weight) should bear a direct mathematical relation to changes in moisture content (expressed as difference between original and final moisture content, each based on sampled weight). If possible changes in dry matter are not involved, this would be true; but the relation is not simple, because the weight changes are based on original fresh weight and the moisture contents are based on fresh weight at time of sampling.

When seeds respire they consume stored food materials, therefore there is a loss of dry material during storage, and this might be expected to be appreciable at high humidity and high temperature.

As stated in the description of methods, each sample of seeds in these studies was weighed at the initiation of the experiments (over 900 samples) and again when it was removed from the storage cham-

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ber. This was done not only to determine change in total weight from gain or loss of moisture, but in the hope that with the moisture determination, total dry matter could be accurately calculated for each sample before and after treatment, and any losses due to treatment determined. Unfortunately, the methods of weighing and sampling, while quite accurate enough for the main purposes of the work, proved inadequate for dependable estimation of dry-matter losses of individual samples. Despite these troubles, the large mass of data collected offered an opportunity to calculate mean tendencies toward dry-matter losses among the several treatments.

A variance analysis was made for the seven species, data for which were suitable for combining. The standard error of a single determination, based on error variance (for interaction between crops, samples, and storage conditions) was $\pm$ 52 mg., while the mean loss for all samples was but 12.5 mg. Obviously, little dependable information can be obtained from such data. Even so, variance due to treatments and to interaction of crops $\times$ treatments was highly significant with reference to error. The high-temperature, high-humidity treatment was the only one showing a highly significant departure in weight of dry matter as compared with weight at the beginning of the experiment. This is true only for the figures relating to the 10 samplings as a group. None of the values from the 110-day sampling alone show a significant departure from zero.

At low humidities and low temperatures in this work there seemed to be no change in percentage of moisture other than that to be accounted for by change in weight. Except at high humidity and temperature, it would seem safe to use change in weight as an index of change in moisture content.

GERMINATION RESPONSE TO STORAGE

EFFECTS OF 32° F. STORAGE

Reference is made to pages 5 and 7, where it was stated that residues of samples, or collateral samples, of seeds subjected to the several treatments were placed in cold storage immediately after the samples were drawn for moisture and germination determinations. The primary objectives of so storing these seeds were: (1) To determine how the moisture content and germinating power of the seeds, as taken from the chambers on the successive dates, might change during several months' storage at 32° F. and 60 percent relative humidity; and (2) to determine whether germination tests on a single species for all these treatments and treatment time intervals, made simultaneously under a single set of conditions, would exhibit a lower error variance as a result of eliminating the uncontrolled variables that are certain to be involved in making successive germination tests.

Both of the objectives were quite successfully attained, the second being possible because there was no important difference in germination of an entire series removed from 32° F. storage and germinated at one time, under a single set of conditions, as compared with the same samples germinated in 11 successive lots over a period of 251 days. While it is true that in most instances there was a significant difference between the 2 groups of germination data, it was always relatively small. The first set of germinations (made successively at intervals) was generally slightly higher than the second (all made at once after storage at 32°), but the reverse sometimes occurred.

Since the seeds from the high-humidity and high-temperature treatment were more or less seriously damaged before being placed in cold storage, it was desired to determine whether they held up as well at 32° F. as did the other lots, which were damaged none or only to a moderate degree. Table 12 presents a comparison of such damaged and sound seeds before and after storage at 32° for a mean time of about 7 months.

TABLE 12.—*Comparison of certain mean results of germination tests from 2 groups of tests, the first extending over 251 days and the second consisting of collateral samples held in cold storage and tested at one time*

Seed	Mean germination of seeds from series of treatments and group tests shown							
	Small samples from cans, treated up to 251 days				Large samples from bags, treated up to 87 days			
	High humidity and temperature		All other treatments		High humidity and temperature		All other treatments	
	First tests	Second tests	First tests	Second tests	First tests	Second tests	First tests	Second tests
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lima bean							64.7	68.2
Kidney bean					91.1	90.5	86.3	90.3
Sweet corn					43.9	49.8	68.6	80.8
Peanut					43.3	41.8	61.2	70.1
Beet	74.7	75.7	84.6	88.1	83.1	82.1	86.0	89.0
Cabbage	73.6	73.8	91.1	[1] 90.3	86.3	[1] 84.5	91.0	91.0
Carrot	72.0	[1] 68.3	90.4	[1] 89.1	85.6	[1] 84.1	90.6	90.4
Onion	21.7	21.4	72.8	[1] 71.8	27.5	28.0	78.9	79.7
Spinach	42.2	42.5	74.2	73.8	48.9	49.1	71.9	70.4
Tomato	82.4	[1] 80.9	91.5	[1] 90.2	85.1	84.1	92.0	91.2
Mean	61.1	60.4	84.1	83.9	66.1	66.0	78.9	82.1

[1] Second test inferior to first test by odds of 19 to 1 or more.

Despite the statistical significance of many of the differences between the tests before and after storage, there was only one case in which the second test was inferior by as much as 2 percent. Thus, for all practical purposes the groups of tests after 32° F. storage may properly be considered as replicates of those made before storage. Tables 19, 20, and 22 to 25 were developed from combinations of these two groups of germination tests. The means are more dependable and the standard errors of the means are lower than for either group alone, although the error variances for the later groups alone were not consistently different from the others.

The procedure of holding lots of seeds at 32° F. after removal from certain treatments at successive time intervals, until a time series is complete, then germinating them all simultaneously, seems to have much to recommend it for studies of comparatively short duration.

EFFECTS OF STORAGE TREATMENTS ON VIABILITY

Tables 13 to 26, inclusive, show the mean percentages of medium to good seedlings in the 10 species of seeds from the 7 storage conditions on 11 dates and the analyses of variance of the data entering into the germination tables.

Footnotes in the tables show the magnitudes of differences required for 19 : 1 odds of significance between single values shown in the tables, between means of storage periods, and between means of storage conditions.

It was originally planned to establish three atmospheric-humidity levels at each of two constant temperatures, holding each level equal

TABLE 13.—*Percentage of normal, mechanically injured, and small seedlings of lima bean after storage of seed under different conditions*

[Means of duplicate 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
10	67.0	70.0	76.0	73.5	75.5	79.5	74.0	73.6
20	74.0	77.5	77.0	80.5	81.5	77.0	80.0	78.2
30	82.5	76.0	78.0	85.0	83.5	73.0	79.0	79.6
40	70.5	74.0	76.5	74.0	74.5	72.0	73.5	73.6
50	64.0	71.0	66.5	73.5	72.5	76.0	70.5	70.6
60	72.5	77.0	72.5	72.0	66.5	76.5	72.5	72.8
70	71.5	69.5	63.0	72.5	68.5	74.5	77.0	70.9
80	44.0	69.0	45.0	72.5	71.0	73.0	67.5	63.1
90	60.0	63.5	62.0	70.0	79.0	75.0	73.5	69.0
110	54.0	65.0	58.5	74.5	59.5	68.0	59.5	62.7
251	26.5	61.0	47.0	61.0	69.0	58.0	62.5	55.0
Mean [2]	62.4	70.3	65.6	73.5	72.8	72.0	71.8	69.9

[1] Minimum differences required for significance are: Between single values, 10.0; between means of storage periods, 3.8; between means of treatments, 3.0 percent.

[2] Exclusive of results for zero time.

TABLE 14.—*Percentage of fully normal vigorous seedlings and mechanically injured seedlings of kidney bean after storage of seed under different conditions*

[Means of duplicate 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
10	88.0	91.0	93.5	92.0	94.0	89.5	96.0	91.6
20	94.0	96.5	96.5	94.0	94.5	93.5	98.0	94.6
30	92.5	92.0	91.5	95.5	96.5	97.5	97.0	94.6
40	85.5	90.0	92.5	93.5	93.5	93.0	95.0	91.9
50	82.5	88.5	90.0	91.0	93.5	92.0	95.5	90.4
60	78.5	90.5	85.5	90.0	90.0	94.0	87.5	88.0
70	83.5	91.0	86.5	87.5	88.5	92.5	89.0	88.4
80	79.5	82.5	70.5	88.0	87.0	86.0	83.5	83.7
90	75.5	86.0	88.0	86.0	87.0	90.5	90.5	86.2
110	59.5	80.5	80.0	82.5	88.0	88.0	81.0	79.9
251	0	56.5	92.0	90.5	79.0	77.5	84.0	74.2
Mean [2]	74.5	88.6	88.4	90.0	91.0	90.3	90.2	87.6

[1] Minimum differences required for significance are: Between single values, 7.2; between means of test periods, 2.7; between means of treatments, 2.3 percent.

[2] Exclusive of results for zero time.

and as nearly constant as possible at both temperatures, in order to evaluate interaction between temperature and humidity. Since the data in tables 1 to 3 show that these conditions were not fulfilled, close comparisons should be made only on the basis of the several conditions that did prevail. It is true that fair indications of the effect of temperature at a given humidity can be determined, but the full usefulness of the design was so impaired by inadequate humidity control that interaction effects can be discussed only with qualifications.

TABLE 15.—*Percentage of normal, vigorous seedlings of sweet corn after storage of seed under different conditions*

[Means of duplicate 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	81.5	81.5	81.5	81.5	81.5	81.5	81.5	81.5
10	76.0	78.0	78.0	75.0	82.5	79.5	76.5	77.9
20	65.5	78.0	79.0	81.5	78.5	83.5	77.0	77.6
30	41.0	78.0	81.5	83.0	77.5	74.0	74.0	72.7
40	36.5	70.0	72.5	73.0	78.0	76.5	71.0	68.2
50	29.0	69.0	75.0	72.5	77.5	75.5	68.5	66.7
60	16.5	65.0	70.0	66.0	71.5	74.0	57.0	60.0
70	13.5	67.5	68.0	63.5	78.5	71.0	62.5	60.4
80	19.5	67.0	70.5	68.5	70.0	72.0	65.5	61.8
90	13.0	68.5	65.0	75.0	84.0	77.5	61.0	63.4
110	12.5	66.5	66.0	58.0	66.0	62.0	50.0	54.5
251	0	66.0	70.0	57.0	59.5	69.0	55.0	53.8
Mean [2]	28.4	70.3	70.9	70.3	74.7	74.0	65.3	65.2

[1] Minimum differences required for significance are: Between single values, 6.7; between means of test periods, 2.5; between means of treatments, 2.1 percent.
[2] Exclusive of results for zero time.

TABLE 16.—*Analysis of variance of germination data entering into tables 13, 14, and 15*

Source of variation	Degrees of freedom	Variance for crops shown [1]		
		Lima bean	Kidney bean	Sweet corn
Total	153	104.4	144.6	341.2
Between treatments	6	[2] 400.2	[2] 759.5	[2] 5,701.6
Between storage periods	10	728.2	554.2	969.5
Treatments × periods	60	72.7	184.3	123.3
Remainder (error)	77	25.0	12.7	11.7

[1] All values highly significant with reference to error.
[2] Significant by odds of more than 99 to 1 with reference to treatments × storage periods.

TABLE 17.—*Percentage of fully normal and small seedlings of peanut after storage of seed under different conditions*

[Means of duplicate 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.				
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent	Warehouse	Mean
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
20	63.0	78.0	83.0	77.0	74.5	77.5	76.0	75.6
40	44.5	80.0	84.5	72.0	80.0	82.5	77.0	74.4
60	9.0	49.5	52.5	55.0	73.0	74.0	55.0	52.6
80	3.5	62.5	72.5	60.5	73.5	77.0	55.5	59.1
110	0	43.0	50.5	75.5	70.5	(?) 42.0	64.0	50.6
251	0	20.0	57.5	40.0	67.5	70.0	34.5	44.0
Mean [2]	20.0	57.0	68.3	66.3	73.2	70.5	60.3	59.4

[1] Minimum differences required for significance are: Between single values, 12.7; between means of test periods, 4.8; between means of treatments, 4 percent.

[2] Exclusive of results for zero time.

TABLE 18.—*Analysis of variance of data on germination of peanut entering into table 17*

Source of variation	Degrees of freedom	Variance
Total	83	540.2
Between treatments	6	3,906.2
Between dates	5	2,374.3
Treatment × dates	30	250.4
Remainder (error)	42	35.1

TABLE 19.—*Percentage of beet balls producing one or more normal seedlings after storage of seed under different conditions*

[Means for four 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.				
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent	Warehouse	Mean
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
10	86.3	84.3	87.5	92.0	91.0	85.3	87.3	87.6
20	86.3	84.5	88.3	87.0	81.8	85.5	85.8	85.6
30	85.5	88.3	88.3	88.3	89.8	89.0	89.5	88.3
40	83.8	88.3	80.0	85.5	87.0	81.3	86.0	84.5
50	77.5	84.5	84.8	84.0	85.0	85.5	89.5	84.4
60	76.5	85.5	86.3	84.8	87.0	84.5	89.3	84.9
70	82.5	86.3	90.8	87.5	89.8	89.5	88.5	87.7
80	79.0	85.8	82.3	86.5	85.0	86.0	84.0	84.1
90	83.0	86.0	89.0	87.3	86.3	87.5	84.5	86.2
110	77.5	88.0	93.3	84.5	86.8	87.3	86.3	86.2
251	8.8	78.8	87.8	86.5	81.3	85.0	85.5	73.4
Mean [2]	75.1	85.5	87.0	86.7	86.4	86.0	86.9	84.8

[1] Minimum differences required for significance are: Between single values, 6.4; between means of treatments, 1.9; between means of storage periods, 2.4 percent.

[2] Exclusive of results for zero time.

TABLE 20.—*Percentage of normal, vigorous seedlings of spinach after storage of seed under different conditions*

[Means of six 100-seed tests][1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.				
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent	Warehouse	Mean
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	73.0	73.0	73.0	73.0	73.0	73.0	73.0	73.0
10	70.8	78.2	81.8	75.8	78.8	76.2	71.0	76.1
20	58.7	72.8	80.2	78.2	75.0	79.3	76.2	74.3
30	57.3	77.0	76.7	77.2	80.0	75.5	73.3	73.9
40	54.7	72.3	75.5	75.2	74.5	76.3	74.0	71.8
50	44.7	75.7	79.8	74.2	71.3	78.2	70.0	70.5
60	44.0	77.0	72.8	71.7	70.0	75.7	62.6	70.5
70	44.3	74.7	76.0	77.0	73.2	75.0	64.5	69.2
80	35.7	73.2	76.8	75.0	74.5	76.7	66.2	68.3
90	32.5	72.7	76.2	74.7	77.7	81.3	65.5	68.0
110	23.2	60.0	76.3	73.0	71.5	70.8	50.6	64.6
251	.3	63.3	75.0	63.2	71.3	72.8	46.8	56.1
Mean[2]	42.4	73.3	77.0	74.1	75.2	77.0	67.3	69.5

[1] Minimum differences required for significance are: Between single values, 5.3; between means of storage periods, 2.0; between means of treatments, 1.0 percent.
[2] Exclusive of results for zero time.

TABLE 21.—*Analysis of variance of data entering into tables 19 and 20*

Source of variation	Data for beet		Data for spinach	
	Degrees of freedom	Mean square[1]	Degrees of freedom	Mean square[2]
Total	307	104.3	443	222.7
Between treatments	6	809.4	6	10,122.7
Between storage periods	10	162.9	10	1,251.5
Between groups of tests	1	808.4	1	10.0
Treatment × storage	60	284.3	60	293.5
Remainder (error)	230	20.2	366	21.3

[1] All values highly significant with reference to error.
[2] All values highly significant with reference to error except that for groups of tests.

TABLE 22.—*Percentage of normal, vigorous seedlings of cabbage after storage of seed under different conditions*

[Means of eight 100-seed tests][1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0
10	88.8	90.0	91.3	91.8	89.3	90.5	91.5	90.4
20	87.5	90.8	92.8	91.9	91.3	92.4	91.2	90.8
30	88.5	90.9	91.4	90.6	90.4	92.3	88.6	90.2
40	83.0	90.5	91.4	90.0	93.3	91.3	91.5	90.3
50	84.8	89.6	92.4	87.9	91.6	90.8	90.5	89.6
60	80.0	90.3	91.3	91.6	92.3	91.6	89.2	89.4
70	79.4	89.6	92.0	87.0	92.8	92.1	88.6	88.9
80	76.5	90.5	93.2	88.5	90.6	91.6	89.7	88.6
90	74.6	89.9	91.9	88.2	90.4	92.9	89.0	88.1
110	66.4	90.0	90.3	88.0	90.5	92.8	88.8	86.8
251	.8	89.3	91.0	88.2	91.6	92.3	88.0	77.3
Mean [2]	73.6	90.1	91.7	89.4	91.3	91.9	89.6	88.2

[1] Minimum differences required for significance are: Between single values, 3.2; between means of treatments, 1.0; between means of storage periods, 1.2 percent.
[2] Exclusive of results for zero time.

TABLE 23.—*Percentage of normal, vigorous seedlings of carrot after storage of seed under different conditions*

[Means of eight 100-seed tests][1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	92.5	92.5	92.5	92.5	92.5	92.5	92.5	92.5
10	89.4	90.5	89.4	91.3	89.6	90.3	90.4	90.1
20	85.1	89.5	90.9	89.0	92.1	90.2	90.3	89.6
30	85.3	91.7	91.1	89.5	90.3	90.8	89.5	89.7
40	82.5	90.0	91.0	88.1	89.1	90.5	88.4	88.5
50	80.5	90.1	90.0	90.1	92.4	90.6	89.3	89.0
60	79.2	89.6	91.1	88.8	89.4	90.1	90.2	88.3
70	76.1	89.0	88.4	92.0	90.8	91.5	89.2	88.1
80	71.0	86.7	89.1	90.8	92.6	88.8	89.4	86.9
90	65.9	89.2	90.9	89.0	90.4	88.0	87.5	86.0
110	55.8	89.4	89.3	87.9	89.9	90.1	88.4	84.4
251	1.0	86.6	89.8	87.8	87.6	90.8	86.5	75.7
Mean [2]	70.2	89.3	90.1	89.5	90.3	90.4	89.0	87.0

[1] Minimum differences required for significance are: Between single values, 3.2; between means of treatments, 1.0; between means of storage periods, 1.2 percent.
[2] Exclusive of results for zero time.

TABLE 24.—*Percentage of normal, vigorous seedlings of onion after storage of seed under different conditions*

[Means of eight 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	80.2	80.2	80.2	80.2	80.2	80.2	80.2	80.2
10	67.8	75.1	80.8	78.9	76.4	70.0	76.1	76.3
20	38.3	77.5	76.8	77.6	78.8	70.5	73.9	71.8
30	30.4	77.0	78.9	77.6	76.3	77.6	74.8	70.4
40	14.0	72.1	79.4	75.0	77.4	78.1	66.9	66.1
50	8.9	72.1	76.5	77.0	79.4	78.2	63.0	65.0
60	3.1	71.0	78.5	75.9	75.6	79.6	53.1	62.4
70	1.5	75.5	77.9	76.4	78.9	77.5	54.3	63.1
80	1.5	71.3	78.4	72.8	77.1	79.3	51.6	61.7
90	.6	66.1	79.4	72.9	80.4	78.9	49.8	61.1
110	0	64.8	78.6	61.4	74.8	73.9	38.1	57.0
251	.1	37.4	72.9	64.3	76.0	74.5	26.5	50.3
Mean [2]	15.1	69.1	78.0	74.3	77.4	77.8	57.1	64.1

[1] Minimum differences required for significance are: Between single values, 4.7; between means of treatments, 1.4; between means of storage periods, 1.8 percent.
[2] Exclusive of results for zero time

TABLE 25.—*Percentage of normal, vigorous seedlings of tomato after storage of seed under different conditions*

[Means of eight 100-seed tests] [1]

Time in storage (days)	Germination after removal from storage conditions shown							
	Temperature 80° F.			Temperature 50° F.			Warehouse	Mean
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	91.8	91.8	91.8	91.8	91.8	91.8	91.8	91.8
10	92.5	92.6	92.4	94.0	92.9	94.0	91.5	92.8
20	85.9	90.6	94.0	91.0	93.8	91.1	91.6	91.1
30	84.8	93.4	93.4	91.2	93.0	93.9	89.5	91.3
40	84.1	91.4	90.9	90.1	93.1	90.5	90.0	90.0
50	82.3	91.1	93.1	92.5	91.8	92.5	86.6	90.0
60	82.4	88.0	90.3	90.0	92.4	92.5	87.1	88.9
70	80.3	87.8	93.1	88.1	93.4	93.9	87.9	89.2
80	79.3	90.3	93.4	88.9	93.6	93.4	88.9	89.7
90	81.9	87.5	92.8	89.9	92.1	93.4	85.8	89.0
110	77.1	87.0	91.5	90.3	89.9	92.6	86.3	87.8
251	68.1	85.0	91.8	86.6	90.5	91.4	83.9	85.3
Mean [2]	81.7	89.5	92.4	90.2	92.4	92.6	88.1	89.6

[1] Minimum differences required for significance are: Between single values, 3.0; between means of treatments, 0.9; between means of storage periods, 1.0 percent.
[2] Exclusive of results for zero time.

TABLE 26.—*Analysis of variance of germination data entering into tables 22, 23, 24, and 25*

Source of variation	Degrees of freedom	Variance for crops shown [1]			
		Cabbage	Carrot	Onion	Tomato
Total	615	128.1	130.1	582.8	28.8
Between treatments [2]	6	[1] 3,720.1	[1] 4,858.2	[2] 45,998.2	[1] 1,325.7
Between storage periods	10	817.6	941.0	2,862.6	215.8
Between groups of tests	1	84.0	484.0	123.7	328.7
Treatments × periods	60	713.0	682.5	606.4	40.9
Remainder (error)	538	10.0	10.3	22.0	9.0

[1] All values highly significant with reference to error.
[2] Significant by odds of more than 99 to 1 with reference to treatments × periods and with reference to error.

HIGH HUMIDITY AT HIGH TEMPERATURE

The most striking point in tables 13 to 26 is that, with the exception of beet, which showed no change through 110 days, all crops soon showed very significant decreases in viability when stored at 80° F. and 75 to 80 percent relative humidity. Sweet corn (fig. 3), onion, and peanut were almost completely destroyed within 60 days, and spinach was very severely damaged. Beans, cabbage, and carrots were injured to a significant extent in 40 to 60 days and showed serious loss after 90 or 110 days. Tomato also showed a small but significant loss after 20 days, but the rate of deterioration was quite gradual up to 251 days. At 251 days kidney bean, sweet corn, cabbage, carrot, peanut, onion, and spinach were all dead or practically dead. Beet germinated less than 10 percent, lima bean was commercially worthless, and only tomato survived over 40 percent.

MEDIUM HUMIDITY AT HIGH TEMPERATURE

At medium humidity (66 percent) at 80° F., the beans, sweet corn, onion, and peanut all showed quite definite loss of viability at 110 days. Significant decreases showed up much later than at high humidity and were far less severe. Definite injury of practical commercial importance was evident in about 3 months under these conditions. At 251 days spinach, onion, sweet corn, and peanut were far below commercial standards.

All crops from the high humidity at 80° F. showed significantly lower viability than those from medium humidity after 110 days and after 251 days.

LOW HUMIDITY AT HIGH TEMPERATURE

Generally, seeds at 80° F. and at low humidity (44 percent) germinated after 110 days as well as or better than those at medium humidity, although peanut, onion, spinach, and tomato were the only kinds significantly better. At 251 days low humidity was definitely superior to medium humidity as a storage condition for many kinds of seeds. Despite the superiority of 44 percent over 66 percent humidity at the high temperature, lima bean, sweet corn, and peanut showed a significant deterioration in 60 to 80 days and onion in 251 days. Lima bean and peanut were definitely below the minimum standard by 251 days. Kidney bean and all the small seeds except onion showed no significant loss at 251 days.

Since it was only the large seeds, germinated in soil in the greenhouse, that showed appreciable loss when stored at 80° and 44 percent humidity for 110 days or less, the question arises as to whether the increasingly adverse germinating conditions might have been respon-

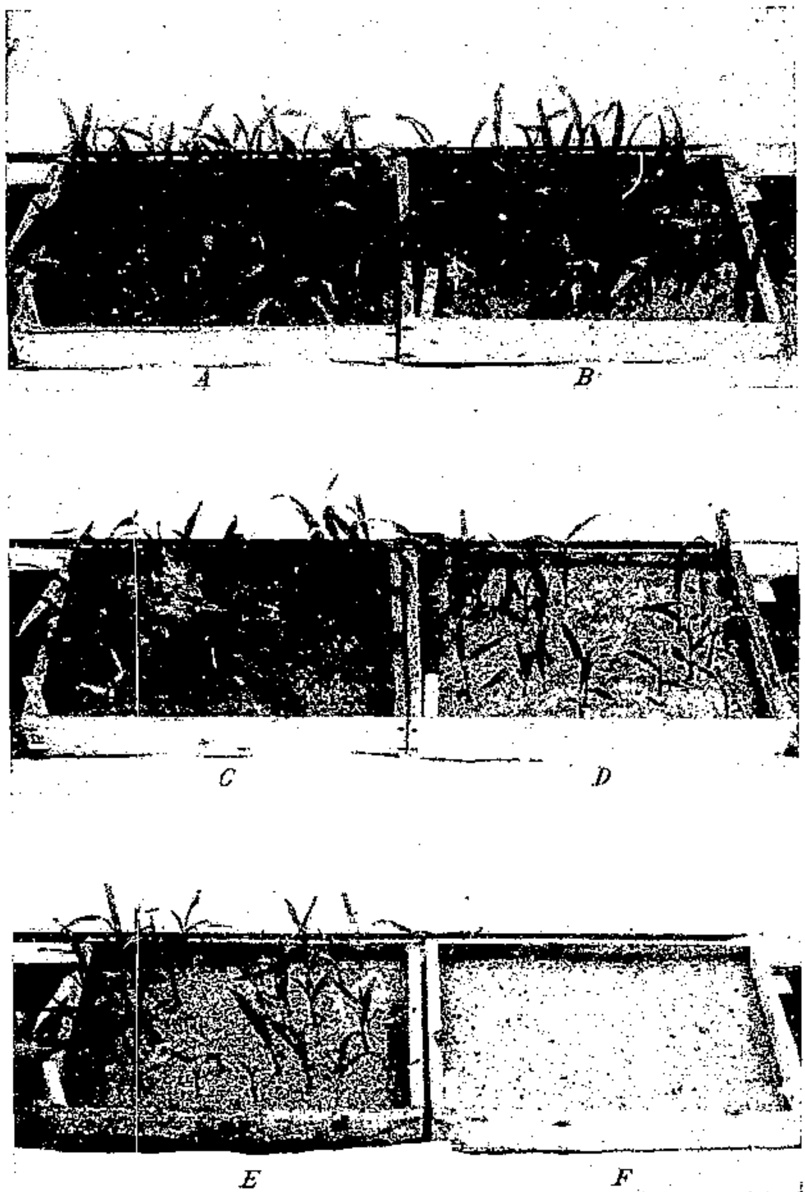

FIGURE 3.—Sweet corn germinated in the greenhouse after seed had been stored at high humidity and 80° F. for the number of days indicated, then held at 32° until germinated in April 1939: *A*, 10 days; *B*, 30 days; *C*, 50 days; *D*, 70 days; *E*, 90 days; *F*, 251 days. Seed placed in storage June 25, 1938.

sible. Lower greenhouse temperatures in the fall before the heat was turned on apparently depressed germination percentage slightly, the first evidence of lower germination appearing in early September, while the days were still quite warm and bright but the nights were cold. The higher germinations in several instances at 251 days than at 70 to 110 days supports this view. The 251-day tests were made in March when the greenhouse was heated.

LOW TEMPERATURE

Of the seed stored at 50° F., only sweet corn showed significant decreases in germination at all three moisture conditions by 110 days. Lima bean and onion showed hardly significant losses in germination at 66 and 51 percent humidity. In no case was the fall in germination serious at 50° storage by 110 days, and the further loss by 251 days was significant only for sweet corn and peanut.

WAREHOUSE STORAGE

Tables 1 and 2 show that the mean temperature and humidity for the first 110 days in the warehouse used in this work were 79° F. and 72 percent, respectively, although the fluctuations were appreciable. From July to October (110 days) temperature ranged from below 60° to above 90° and humidity varied from 60 to 90 percent. The mean conditions for that period were roughly similar to those of the high-temperature room, with humidity between the two levels artificially maintained around 78 and 66 percent. From these considerations one might expect the behavior of the seeds to be intermediate between the high- and the medium-humidity series at 80° F. and perhaps closer to the medium. The mean moisture content of the seeds was actually very similar to that of seeds in the latter chamber. During late fall and winter the warehouse was, of course, cold, similar to the low-temperature room, but with both temperature and humidity fluctuating widely.

Considering means of all 11 samples of each species at each treatment and also the final germination shown in table 28, the viability results for warehouse storage were significantly different from medium humidity at 80° F. for only three kinds of seed—sweet corn, spinach, and onion. In these instances the warehouse lots were markedly inferior, individual significant differences occurring at the last three to five samplings. The rapid rate of deterioration of onion under warehouse conditions was especially striking; good strong seedlings dropped from 80 down to approximately 50 percent in 60 days. The mean temperature during that period was well above 80° and humidity from 62 to 75 percent. With cooler weather, despite an increase in humidity, the rate of deterioration in onion (table 24) decreased, and the viability held for another month before dropping much more. In the high humidity at 80°, germination was apparently down to about 50 percent in only 2 weeks, in contrast to 60 days for the warehouse seeds. Sweet corn also deteriorated rapidly under these warehouse conditions (table 15).

RELATIONSHIPS TO TIME OF STORAGE

The changes in viability during storage at the various conditions are summarized from different viewpoints in tables 27 and 28. Seed loses its practical value for planting long before all of the seed is dead.

TABLE 27.—*Summary of results of seed-germination tests showing for the various storage conditions the mean moisture content of the seed and the approximate time for viability to fall significantly and for viability to fall below an arbitrary minimum standard*

Seed	Estimated initial viability	Minimum loss to show significance	Minimum standard viability	Results under indicated storage conditions											
				High humidity			Medium humidity			Low humidity			Warehouse		
				Moisture	Time to significant loss	Time to minimum standard	Moisture	Time to significant loss	Time to minimum standard	Moisture	Time to significant loss	Time to minimum standard	Moisture	Time to significant loss	Time to minimum standard
	Percent	*Percent*	*Percent*	*Percent*	*Days*	*Days*	*Percent*	*Days*	*Days*	*Percent*	*Days*	*Days*	*Percent*	*Days*	*Days*
TEMPERATURE 80° F.															
Lima bean	80	10.0	70	15.6	75	75	11.3	80	80	8.8	70	70	12.1	100	100
Kidney bean	97	7.2	80	15.4	40	80	10.8	110	([1])	7.4	([1])	([1])	11.7	90	([1])
Sweet corn	82	6.7	70	12.9	15	20	10.2	40	50	7.5	60	250	10.7	30	50
Peanut	83	12.7	70	8.2	15	15	5.6	60	60	4.3	80	80	6.2	60	60
Beet	86	6.4	75	15.0	110	150	9.9	250	([1])	7.2	([1])	([1])	10.8	([1])	([1])
Cabbage	93	3.2	80	10.1	10	70	7.3	250	([1])	5.9	([1])	([1])	7.8	110	([1])
Carrot	92	3.2	75	12.6	20	80	9.0	200	([1])	6.5	([1])	([1])	9.7	90	([1])
Onion	80	4.7	70	13.2	6	10	10.3	50	90	7.5	200	([1])	10.3	30	40
Spinach	77	5.3	65	14.3	15	20	11.2	110	200	8.5	([1])	([1])	11.8	60	110
Tomato	93	3.0	80	11.2	20	110	8.9	90	([1])	6.9	([1])	([1])	9.4	50	([1])
TEMPERATURE 50° F.															
Lima bean	80	10.0	70	14.6	150	150	12.2	110	110	10.6	110	110	------	----------	----------
Kidney bean	97	7.2	80	15.4	70	([1])	11.8	110	([1])	10.0	110	([1])	------	----------	----------
Sweet corn	82	6.7	70	13.7	50	60	11.6	110	110	9.8	110	200	------	----------	----------
Peanut	83	12.7	70	8.2	125	125	6.2	200	200	5.6	250	250	------	----------	----------
Beet	86	6.4	75	15.0	([1])	([1])	10.4	([1])	([1])	8.8	([1])	([1])	------	----------	----------
Cabbage	93	3.2	80	10.5	70	([1])	7.8	([1])	([1])	6.4	([1])	([1])	------	----------	----------
Carrot	92	3.2	75	13.6	110	([1])	9.8	250	([1])	7.9	([1])	([1])	------	----------	----------
Onion	80	4.7	70	13.8	80	110	10.7	([1])	([1])	9.0	250	([1])	------	----------	----------
Spinach	77	5.3	65	15.0	200	250	12.0	([1])	([1])	10.7	([1])	([1])	------	----------	----------
Tomato	93	3.0	80	12.2	250	([1])	9.7	([1])	([1])	8.4	([1])	([1])	------	----------	----------

[1] In these instances there was no significant loss in germination, or viability remained above the arbitrary minimum standard during the 251 days' duration of this short-time study.

It is of interest to know how long seed will maintain a germination high enough to be of practical value. Therefore in table 27 arbitrary minimum standards of viability are presented for each kind of seed, together with estimates from tables 13 to 26 of the length of storage at the different conditions before viability had fallen to this arbitrary standard. These periods are influenced not only by the susceptibility of the seed to injury but also by the original quality of the seed. Sweet corn (fig. 3), peanut, onion, and spinach at high humidity and high temperature lost their practical value in comparatively a few days, while beet remained above this arbitrary value over 110 days.

In table 27 is also presented the length of time required to show a significant loss of viability at each condition of storage, together with the mean moisture content of the seed at each storage condition. In general there was a decided increase in time before significant loss was apparent with decrease in humidity or decrease in temperature.

In table 28 the estimated germination values after 110 and 251 days of storage are given. Since germination values are subject to error of determination, estimated values, based on the trend of the curve for successive tests, are given rather than the result of the last test.

TABLE 28.—*Summary of germination results in tables 13 to 26, showing the estimated values at 110 and 251 days, based on the general trend of germination values for successive tests*

Seed	Initial viability (estimated)	Minimum loss to show significance	Estimated viability for indicated storage condition and period[1]									
			Temperature 80° F.					Temperature 50° F			Warehouse	
			Humidity 78 percent		Humidity 66 percent		Humidity 44 percent, 110 days	Humidity 81 percent, 110 days	Humidity 66 percent, 110 days	Humidity 51 percent, 110 days	110 days	251 days
			110 days	251 days	110 days	251 days						
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Lima bean	80	10.0	55	25	65	60	60	72	70	70	65	60
Kidney bean	97	7.2	65	0	85	85	90	90	88	88	85	85
Sweet corn	82	5.7	15	0	68	65	70	65	70	72	60	55
Peanut	83	12.7	0	0	45	30	60	70	70	70	60	35
Beet	86	6.4	80	8	85	78	86	86	86	86	86	86
Cabbage	93	3.2	68	1	90	90	90	88	90	92	88	88
Carrot	92	3.2	55	1	90	86	90	88	90	90	88	86
Onion	80	4.7	0	0	64	38	78	68	75	75	38	26
Spinach	77	5.3	25	0	70	65	75	73	75	77	60	48
Tomato	93	3.0	77	68	87	85	92	90	90	92	86	84

[1] Where values for 251 days are not given there were no appreciable losses of viability between 110 and 251 days at that storage condition.

Tables 27 and 28 should be studied together. For example, at high temperature sweet corn and tomato each showed significant loss of germination in 20 days, but sweet corn had fallen below the arbitrary useful value in this time and almost completely lost its viability at 110 days, while tomato did not fall below the arbitrary standard until 110 days, and this value was only slightly below the standard. It is evident that the different kinds of seeds are not equally sensitive to moisture content. One of the most striking differences is between kidney bean and peanut; the former was only moderately affected at high temperature with over 15-percent moisture, while germination was completely lost in the latter with only 8.2-percent moisture. On the other hand, the apparent differences in response of cabbage and onion at given temperatures and humidities are in part evened up when comparison is made of lots with approximately equal moisture contents.

DEHYDRATION STUDIES

The preceding sections have shown how rapidly 10 different vegetable seeds will absorb moisture when exposed in small containers to different conditions, and what the probable consequences of that high-moisture content will be when the seed is held within specified temperature ranges. Indications are also given regarding the probable rate of moisture loss from seeds stored in small containers with access to air of low humidity. It is not known how rapidly these seeds will absorb or give up moisture when packed, for example, in 100-pound cotton bags and stacked in piles. That is another large problem to be worked out. It does seem clear, however, that seeds will absorb just about as much atmospheric water, possibly more, at low temperature as at high temperature, given equal relative humidities and a few weeks' time.

Seeds stored in the North (or in cold storage) at perfectly safe temperatures may develop moisture contents that will be quickly disastrous upon a marked rise in temperature in storage, in transit, or after the seed is delivered to a buyer in a warm locality. The present section presents the results of efforts to reduce quickly very harmful percentages of moisture to comparatively harmless levels without injuring the viability of the seed during the process. The methods and equipment used were described earlier.

REMOVAL OF EXCESS MOISTURE

Table 29 shows (opposite zero time) the moisture content that the seeds had attained in the storage chambers at the time each lot was removed for drying. It also shows (opposite 150° and 120°) the moisture remaining after the seeds were dried for the times indicated. The data are presented in three groups of kinds of seeds according to the approximate time required to dry them down to a predetermined weight. Regardless of the moisture content of the seed as removed from the high-humidity chambers, it was the purpose to leave them in the driers until they had been restored to the approximate moisture content (or somewhat below it) shown at the beginning of these storage studies. This level was arbitrarily chosen and for some seeds may have been rather too high for safe storage at high temperature.

Two successive dehydrations were carried out with separate series of seeds from the high-humidity chambers (78 and 81 percent) at 80° and 50° F., respectively, to determine the feasibility of quick drying of seeds that have become too high in moisture but that may not yet be seriously damaged. For obtaining a comparison of the effects of heat alone (compared with heat plus high moisture of seed), seeds from the medium- and low-humidity chambers at 80° and 50° were subjected to the same procedure. Regardless of their moisture content, which was medium to low when they were put in the drier, they were heated the same length of time required to reduce the too moist seeds to a safe level.

It should first be noted that the moisture contents of the seeds kept in bags in 400- to 2,000-gm. lots in the chambers agreed quite closely with those kept in small containers (table 6).

TABLE 29.—*Effect of artificial drying on moisture content of seeds after removal from different storage conditions*

[Moisture expressed as percent of total weight of seed as sampled]

SEEDS DRIED 3 HOURS[1]

Dehydration: Approximate temperature (° F.)	Dehydration: Typical time	Seed	Moisture content of seeds from different storage conditions shown[2]: H H 24 days	H H 55 days	H L 48 days	H L 79 days	Mean[3]	L L 80 days	L H 58 days	M H 86 days	M L 87 days	Original moisture[4]
	Hours		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
--------	0	Lima bean	15.7	15.9	14.2	15.5	15.3	10.7	8.4	11.7	12.6	11.1
--------	0	Kidney bean	16.0	15.4	16.3	16.4	16.0	9.9	7.4	10.8	12.2	11.6
		Mean	15.8	15.6	15.2	16.0	15.6	10.3	7.9	11.2	12.4	------
150	3	Lima bean	12.1	10.8	10.0	11.5	11.1	9.1	7.3	9.7	10.6	11.1
150	3	Kidney bean	11.3	10.6	11.1	10.9	11.0	8.0	6.5	8.1	9.1	11.6
		Mean	11.7	10.7	10.6	11.2	11.1	8.6	6.9	8.9	9.8	------
120	3	Lima bean	13.4	13.2	12.5	13.4	13.1	9.8	8.1	10.8	11.7	11.1
120	3	Kidney bean	13.3	11.6	11.9	12.5	12.3	8.9	6.9	9.7	10.5	11.6
		Mean	13.4	12.4	12.2	13.0	12.8	9.4	7.5	10.2	11.1	------

SEEDS DRIED 1¼ TO 1½ HOURS[1]

Temp. (° F.)	Time	Seed	H H 24 days	H H 55 days	H L 48 days	H L 79 days	Mean	L L 80 days	L H 58 days	M H 86 days	M L 87 days	Original moisture
------	0	Peanut	9.0	8.1	8.3	8.1	8.4	5.4	4.4	5.9	6.4	6.1
150	1¼	do	6.0	5.8	5.4	5.4	5.6	4.1	3.3	4.2	4.3	6.1
120	1½	do	6.2	5.8	5.9	6.5	6.1	4.4	3.6	4.6	5.0	------

SEEDS DRIED ½ TO 1 HOUR[1]

Temp. (° F.)	Time	Seed	H H 24 days	H H 55 days	H L 48 days	H L 79 days	Mean	L L 80 days	L H 58 days	M H 86 days	M L 87 days	Original moisture
--------	0	Sweet corn	13.8	12.9	14.3	14.0	13.8	9.8	7.4	10.5	11.9	12.0
--------	0	Beet	15.1	14.7	16.4	15.5	15.4	8.8	7.3	10.2	10.8	10.1
--------	0	Cabbage	10.4	10.0	10.8	10.7	10.5	7.0	5.7	7.5	8.0	7.6
--------	0	Carrot	13.7	12.4	14.3	13.8	13.6	8.3	6.8	9.2	10.2	9.1
--------	0	Onion	13.5	12.9	14.3	13.9	13.6	9.4	7.8	10.0	10.7	10.1
--------	0	Spinach	14.3	14.2	15.3	15.4	14.8	10.8	9.7	11.5	12.2	11.4
--------	0	Tomato	11.0	11.3	12.5	12.4	11.8	8.8	7.3	9.0	9.9	9.2
		Mean	13.1	12.6	14.0	13.7	13.4	9.0	7.3	9.7	10.6	------
150	½	Sweet corn	9.1	10.4	10.9	11.9	10.6	8.8	6.6	9.4	10.2	12.0
150	½–¾	Beet	6.2	9.3	9.2	9.0	8.4	6.4	5.6	5.8	6.3	10.1
150	½	Cabbage	4.7	6.5	6.8	7.5	6.4	5.2	4.3	3.5	5.9	7.6
150	½	Carrot	5.2	7.9	8.7	9.2	7.8	6.9	5.6	6.3	7.1	9.1
150	½	Onion	6.2	8.8	8.4	10.1	8.4	7.4	6.3	7.5	7.9	10.1
150	½	Spinach	7.1	10.3	10.4	11.4	9.8	8.5	7.5	9.3	9.0	11.4
150	¼	Tomato	5.4	7.7	2.37	7.8	5.9	6.5	5.9	6.5	6.3	9.2
		Mean	6.3	8.7	8.17	9.6	8.2	7.1	6.0	7.2	7.5	------
120	1	Sweet corn	11.0	11.0	10.9	11.5	11.1	8.8	7.2	9.3	10.1	12.0
120	¾–1	Beet	8.3	9.4	7.9	9.0	8.6	6.2	6.0	7.3	6.8	10.1
120	½–¾	Cabbage	6.1	6.5	7.1	7.4	6.8	5.8	5.2	5.8	5.9	7.6
120	1	Carrot	7.3	9.2	7.8	8.3	8.2	7.2	6.6	6.6	6.9	9.1
120	½	Onion	7.4	8.7	9.7	10.0	9.0	7.8	7.0	8.3	8.6	10.1
120	¾	Spinach	9.3	10.2	11.8	11.4	10.7	9.3	8.0	9.4	9.1	11.4
120	½	Tomato	6.7	8.3	8.4	8.6	8.0	7.0	6.8	7.4	7.3	9.2
		Mean	8.0	9.0	9.1	9.5	8.9	7.4	6.8	7.7	7.8	------

[1] Limits of sampling error estimated at ±1.2 percent moisture.
[2] The first letter in each box head denotes humidity—high, medium, or low. The second letter denotes temperature—high or low.
[3] Mean of 4 samples from high-humidity storage.
[4] Moisture content of seed at start of experiment, shown for comparison.
[5] Limits of sampling error estimated at ±1.7 percent moisture.

Although drying time, temperatures, and rates of air flow could not be controlled exactly alike for the successive runs of seeds, they were roughly the same for each. Table 29 shows a rather definite tendency for the small seeds to retain slightly more water after quick drying the longer they have been held at high humidity. Part of this apparent effect may be due to inequalities in the drying treatment. The trend, however, is strongly suggested.

The moisture data for each group of kinds of seed were analyzed by the variance method to derive estimates [5] of variation not accounted for, this to be used in gaging the operator's success in stopping drying at the desired points. Discrepancies of less than 1.2 percent for the 3-hour group, and for peanuts, and less than 1.7 percent among the small seeds are estimated to be within the limits of error for odds of 19 to 1.

It will be noted that as much as 3 hours' heating at 120° F. did not always suffice to reduce the moisture content of the beans from high-humidity chambers to their original levels. It is further interesting that 3 hours at 150° brought the moisture of beans to no lower level than existed in the low-humidity lots upon removal from storage.

In many cases the sweet corn and small seeds were dried below the desired level by heating at 150°, but the results in general were satisfactory. Differences in drying rate in the two tunnels resulted from differences in rate of air flow and aspiration effect as well as in temperature; thus only limited practical recommendations can be made from these trials. Their main value is in showing the practicability of quick partial dehydration of certain seeds and the tolerance of those seeds to the requisite drying temperatures. The efficiency of a given temperature can be vastly increased over that obtained here by the use of high-speed, turbulent air currents and agitation of the seeds in the drier, thus greatly reducing the time that the seeds need be exposed to high temperature.

MOISTURE CHANGES AT 32° F. STORAGE

Duplicate samples of the seeds from the dehydration studies were weighed, placed in paper bags, and stored at 32° F. at approximately 60 percent relative humidity for later simultaneous germination tests. Upon removal from cold storage the seeds were reweighed to determine weight changes. Approximate moisture contents of the seeds from cold storage were estimated from the weight changes. The results presented in table 30 show that for most kinds of seeds the final moisture reached at 32° by those previously stored at high humidity is significantly higher for lots not dried. For seeds previously stored at medium and low humidities there is no significant difference in moisture between nondried and dried for any kind of seed. It might seem from these results that drying seeds with a high moisture content reduced their power to absorb moisture later. However, comparison of the initial and final moisture indicates that dried seeds from high humidities had about the same moisture when placed at 32° as nondried seeds from medium and low humidities, and that both had reached about the same moisture level when these data were recorded. It would seem, therefore, that the final moisture observed depended on the moisture content when placed at 32° rather

[5] The "errors" on which these values are based are not "true error," since no replications were involved. They are high-order interactions, probably of about the same magnitude that a true error would be.

than on previous treatment. It is probable that the time of storage was too short for the seeds to reach their final equilibrium of moisture under the particular conditions of storage.

A comparison of the results in table 30 with those in table 11 shows comparable moisture changes, although in one case the seeds were stored at 32° in paper bags and in the other in tin cans with a perforation in the cover.

TABLE 30.—*Summary of estimated moisture contents attained at 32° F. and 60 percent relative humidity by seeds previously exposed to different humidity treatments and then dried before storing*

[Time of storage at 32° F., 6 to 8 months]

Seed	Drying treatment	Moisture content of seeds previously stored at—				Mean final moisture [3]
		High humidity		Medium and low humidity		
		Initial moisture [1]	Final moisture [2] [3]	Initial moisture [1]	Final moisture [2] [3]	
	° F.	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lima bean	None	15.3	13.5	10.9	12.9	13.3
	150	11.1	12.5	9.2	12.4	12.5
	120	13.1	13.3	10.1	12.7	13.0
Kidney bean	None	16.0	13.0	10.1	12.2	12.7
	150	11.0	12.1	7.9	11.3	11.4
	120	12.3	12.5	9.0	12.0	12.3
Sweet corn	None	13.8	12.7	9.9	11.6	12.1
	150	10.6	10.9	8.8	11.0	10.9
	120	11.1	11.6	8.9	11.4	11.5
Peanut	None	8.4	7.2	5.5	6.4	6.8
	150	5.7	6.3	4.0	6.3	6.3
	120	6.1	6.4	4.4	6.4	6.4
Beet	None	15.6	13.9	9.3	10.9	13.1
	150	8.4	10.6	6.0	10.3	10.5
	120	8.7	10.8	6.7	10.6	10.7
Cabbage	None	10.5	10.0	7.1	8.0	9.0
	150	6.4	7.6	5.2	7.8	7.7
	120	6.8	7.9	5.7	7.9	7.9
Carrot	None	13.6	12.5	8.6	9.8	11.1
	150	7.8	8.9	6.5	9.7	9.3
	120	8.2	8.8	6.8	9.8	9.3
Onion	None	13.7	13.2	9.5	11.0	12.1
	150	8.4	10.2	7.3	10.9	10.5
	120	9.0	10.7	7.9	11.0	10.8
Spinach	None	14.8	14.6	10.8	12.3	13.4
	150	9.8	11.5	8.6	12.1	11.8
	120	10.7	12.0	9.0	12.2	12.1
Tomato	None	11.8	11.7	8.8	9.9	10.8
	150	7.1	8.7	6.3	9.5	9.1
	120	8.0	9.2	7.1	9.7	9.4
Mean [3]	None	13.3	12.4	9.0	10.5	11.4
	150	8.6	9.9	7.0	10.1	10.0
	120	9.4	10.3	7.6	10.4	10.3

[1] Actual moisture determination on samples before being placed in 32° storage.
[2] Moisture content estimated from changes in weight at 32° F.
[3] Between single values for final moisture content, differences as great as 1.0 percent are significant; between means in the last column, 0.7; between means at bottom of table, 0.6 percent.

EFFECT OF ARTIFICIAL DRYING ON VIABILITY OF SEEDS

Tables 31 and 32 show the results of germination tests on seed samples drawn immediately before and immediately after dehydration. It will be recalled (pp. 6 and 7) that these samples were drawn in duplicate, one to be germinated at once and the second to be stored at 32° F. for germination 7 to 8 months later.

TABLE 31.—*Effect of artificial drying on viability of bean, sweet corn, and peanut seed after being stored under different conditions*

[Samples for germination accumulated at 32° F. and tested simultaneously, in quadruplicate, in the greenhouse, April 1939]

Seed	Drying treatment	Germination of seeds from storage at[1]— Humidity 75 to 81 percent				Humidity 66 percent		Humidity 44 to 51 percent	
		80° F., 24 days	80° F., 55 days	50° F., 48 days	50° F., 79 days	80° F., 86 days	50° F., 87 days	80° F., 56 days	50° F., 80 days
	° F.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Lima bean	None	68.8	63.2	64.2	65.3	71.8	64.0	68.7	75.0
	150	66.8	46.0	50.0	65.8	62.8	66.2	70.3	71.2
	120	68.8	65.8	68.8	68.0	62.0	65.3	71.7	65.5
	Mean	68.0	58.3	64.0	66.3	65.5	65.2	70.2	70.6
Kidney bean	None	94.5	86.5	94.0	89.5	86.3	89.3	90.8	92.5
	150	84.5	57.8	88.8	90.0	88.7	89.7	91.0	92.2
	120	86.8	87.5	88.5	88.8	89.0	83.4	91.5	88.5
	Mean	88.6	77.2	90.4	89.4	88.0	87.5	91.1	91.1
Sweet corn	None	65.3	34.3	80.5	77.5	78.8	80.5	85.8	81.8
	150	66.5	37.5	70.0	79.0	79.2	80.2	83.5	80.8
	120	67.5	40.5	79.2	78.5	79.2	78.2	84.8	80.2
	Mean	66.4	37.4	76.6	78.3	79.1	79.6	84.7	80.9
Peanut	None	66.0	17.5	82.2	61.0	58.0	68.2	71.0	80.5
	150	51.0	8.2	49.0	29.2	44.0	55.2	81.0	80.5
	120	54.5	12.8	74.2	60.5	45.5	61.8	77.0	74.0
	Mean	57.2	12.8	68.5	50.3	49.2	61.8	76.3	78.2

[1] Minimum differences required for significance between single values and means respectively for the several crops are: Lima bean, 7.9 and 4.6; kidney bean, 4.8 and 2.8; sweet corn, 6.3 and 3.6; peanut, 7.2 and 4.2 percent.

When the samples for the large seeds placed in storage at 32° F. were germinated in the greenhouse during April 1939 while the houses were heated, the results with many lots were definitely quite superior to those obtained in the preceding late summer and early fall. These results, as well as those of the 257-day samples from the seven storage chambers (p. 28), emphasized clearly that certain of the fall-germination series had suffered seriously from adverse germination conditions in the greenhouse that were not plainly evident at the time. It is believed that the seeds germinated after holding in cold storage after dehydration provide a far more dependable comparison of the treatments than those germinated at once. Table 31 therefore contains data from only the later set of germinations. The variance analyses are shown in table 33.

TABLE 32.—*Effect of artificial drying on viability of 6 kinds of seed after being stored under different conditions*

[Figures represent means of four germinations made July to September as drying was done, plus four more from seed accumulated at 32° F. and tested in April 1939]

Seed	Drying treatment	Germination of seeds from storage at[1]—							
		Humidity 75 to 81 percent				Humidity 66 percent		Humidity 44 to 51 percent	
		80° F., 24 days	80° F., 55 days	50° F., 48 days	50° F., 79 days	80° F., 80 days	50° F., 87 days	80° F., 56 days	50° F., 80 days
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Beet	None	84.8	80.6	87.0	89.6	87.4	90.0	86.1	84.9
	150	87.8	77.4	86.6	88.6	85.4	87.1	87.8	83.8
	120	86.1	79.1	84.5	87.6	86.0	87.0	87.4	86.5
	Mean	86.1	79.0	86.0	88.6	86.5	88.0	87.1	85.0
Cabbage	None	88.8	82.0	80.3	89.0	91.5	91.5	91.1	92.4
	150	87.8	81.9	90.0	91.0	91.1	91.8	91.0	90.6
	120	89.6	81.3	91.5	89.4	90.9	92.5	94.8	90.9
	Mean	88.7	81.7	90.6	90.1	91.2	91.9	92.6	91.3
Carrot	None	89.8	80.0	90.3	88.4	91.3	91.1	91.9	90.4
	150	87.0	82.4	89.0	87.9	90.8	89.4	89.4	89.6
	120	87.9	83.6	87.9	89.5	88.0	90.1	88.1	90.8
	Mean	88.6	82.0	89.0	88.6	90.0	90.2	89.8	90.3
Onion	None	50.4	4.9	81.3	79.8	67.9	76.9	82.5	81.5
	150	45.0	5.6	77.4	79.4	73.1	81.6	82.4	84.4
	120	45.3	5.1	77.3	78.9	73.9	79.8	79.9	80.5
	Mean	46.9	5.2	78.7	79.3	71.6	79.4	81.6	82.1
Spinach	None	61.5	36.5	69.3	66.1	69.4	75.8	75.1	71.4
	150	62.5	38.4	68.6	70.3	72.3	75.4	76.1	73.0
	120	61.1	43.5	71.4	73.1	71.5	78.3	79.1	75.5
	Mean	61.7	39.5	69.7	69.9	71.0	76.5	76.8	73.3
Tomato	None	86.9	82.4	93.0	89.8	88.1	92.1	93.4	93.4
	150	84.6	82.7	89.6	90.0	89.3	92.6	93.5	95.5
	120	86.4	82.4	91.0	89.8	89.1	94.4	93.9	94.6
	Mean	86.0	82.5	91.4	89.8	88.8	93.0	93.6	94.5

[1] Minimum differences required for significance between single values and means respectively for the several crops are: Beet, 4.4 and 2.6; cabbage, 3.6 and 2.0; carrot, 3.32 and 1.9; onion, 4.6 and 2.7; spinach, 4.8 and 2.8; tomato, 3.2 and 1.8 percent.

TABLE 33.—*Summary of analyses of variance of dehydrated seed lots germinated upon dehydration and after storage at 32° F. and at room temperature*

[See tables 31, 32, and 34]

LIMA BEAN

Source of variation	Degrees of freedom[1]	Variance for data on seeds stored as shown		
		Not stored	32° F. storage	Room storage
Treatments	7	1,347.5	183.8	
Dehydrations	2	482.5	157.2	
Treatment × dehydration	14	94.4	91.1	
Error	72	16.0	31.1	

KIDNEY BEAN

Source of variation	Degrees of freedom[1]	Not stored	32° F. storage	Room storage
Treatments	7	656.1	245.1	
Dehydrations	2	426.5	205.2	
Treatment × dehydration	14	51.0	166.4	
Error	72	11.7	11.7	

[1] Total degrees of freedom is 95 for each crop or separate analysis in the table.

TABLE 33.—*Summary of analyses of variance of dehydrated seed lots germinated upon dehydration and after storage at 32° F. and at room temperature*—Contd.

SWEET CORN

Source of variation	Degrees of freedom [1]	Variance for data on seeds stored as shown		
		Not stored	32° F. storage	Room storage
Treatments	7	2,842.8	2,795.9	
Dehydrations	2	41.5	17.0	
Treatment × dehydration	14	30.7	25.0	
Error	72	18.4	20.2	
PEANUT				
Treatments	7	4,518.2	5,200.9	
Dehydrations	2	1,675.8	1,425.0	
Treatment × dehydration	14	243.1	284.8	
Error	72	43.5	26.1	
BEET				
Treatments	7	74.5	245.2	206.6
Dehydrations	2	11.3	4.2	40.8
Treatment × dehydration	14	18.0	4.9	10.0
Error	72	19.0	14.3	10.3
CABBAGE				
Treatments	7	78.9	230.3	777.3
Dehydrations	2	4.4	1.7	6.8
Treatment × dehydration	14	19.7	8.2	8.8
Error	72	11.1	12.2	12.3
CARROT				
Treatments	7	55.8	134.7	1,640.9
Dehydrations	2	2.5	24.1	7.2
Treatment × dehydration	14	17.1	13.3	23.2
Error	72	10.9	10.2	13.8
ONION				
Treatments	7	8,804.6	8,779.0	11,528.3
Dehydrations	2	7.9	11.1	3.9
Treatment × dehydration	14	40.1	24.8	9.5
Error	72	18.8	19.5	27.1
SPINACH				
Treatments	7	1,897.8	1,725.4	2,815.4
Dehydrations	2	90.2	116.3	61.9
Treatment × dehydration	14	17.3	16.3	70.1
Error	72	21.9	23.7	25.0
TOMATO				
Treatment	7	209.9	206.2	156.1
Dehydrations	2	1.6	5.3	1.8
Treatment × dehydration	14	12.1	13.6	5.9
Error	72	10.0	9.2	10.1

Unlike the greenhouse germinations, no difficulties were encountered in maintaining closely comparable conditions in the laboratory germinators. Most seeds germinated there in April after storage at 32°

showed percentages nearly identical with those germinated immediately after dehydration. Therefore both lots of data have been combined in table 32.

In general, the error variances in the later group of germinations were nearly the same as in the earlier (table 33), despite the wide discrepancies in the means for many of the greenhouse-germinated lots.

Table 31 shows that lima bean and kidney bean from the high-temperature high-humidity chamber were rather seriously damaged by the prolonged heating incidental to reducing moisture content. Although the moisture content was as high or higher in the beans from the high-humidity low-temperature chambers, when they were put in the drier they were not definitely injured. This indicates that in beans the mere presence of high moisure alone was not responsible for the damage by heat, but that the seeds from 80° F. and high-humidity chamber had undergone an incipient deterioration that became evident after the exposure of the seeds to the heat.

Table 31 shows that lima bean and sweet corn were practically uninjured by heating at 150° F. after 24 days' storage at high humidity and 80°; but all kinds except sweet corn were seriously damaged by the same heat treatment after remaining another month at those storage conditions.

Sweet corn was definitely injured in only one instance—seed held 55 days at high humidity and 50° F. It required but a relatively short period to become sufficiently dry, so was not exposed to heat as long as the beans and peanuts.

Peanuts appear especially sensitive to heat, even with only moderate amounts of moisture present. Only the low-humidity lots escaped injury. In the high-humidity lots the 120° F. temperature was harmful to peanut, while it did not damage the other kinds of seeds of any storage lot. The data for peanut illustrate very clearly the increasing sensitivity to heat with increasing moisture content of seed, higher temperature of storage, and longer exposure to an adverse storage condition.

Of the small seeds (table 32) none appear to have been significantly damaged by heat, although it is clear that onion and spinach from the high-humidity chamber at 80° F. were badly deteriorated both at 24 and 55 days. Why was not incipient deterioration made evident in these small seeds, or existing deterioration exaggerated by the heat treatment, as in beans and peanut (table 31)? These small seeds probably were subjected to temperatures of 120° or 150° only a few minutes. They gave off their moisture so quickly that a cooling effect was doubtless produced, delaying the rise in seed temperature; they were usually removed from the driers at the end of 30 minutes.

Details of the variance analysis of these results are included in table 33.

EFFECTS OF LABORATORY STORAGE

Although it was not practicable to include in these investigations any plans for studying rapid deterioration of seeds after removal from the seven storage conditions described (page 3), a few incidental observations of this sort were made. The excess of seed from the germination tests on the dehydrated lots was kept in manila envelopes in a filing cabinet in the laboratory in an "air-conditioned" building for a mean time of about 7 months. Germination tests were then made, one species at a time, upon these room-stored seeds, simultaneously with tests on the duplicate samples that had been held at 32° F. Excess seed stored at room temperature were available only for the six kinds of small seeds; but since these results are of considerable interest, they are summarized in table 34. The analyses of variance of the original data are included in table 33.

TABLE 34.—*Effect of storage at room temperature versus cold storage (32° F.) 6 to 8 months after removal from previous humidity and temperature treatments*

[Means of twelve 100-seed tests, which were quadruplicate tests of nondried seeds and seeds dried at 150° and 120° F.]

Seed	Germination of seeds held in laboratory and in cold storage after previous conditions shown[1]							
	Previous storage humidity 75 to 81 percent							
	24 days at 80°		55 days at 80°		48 days at 50°		79 days at 50°	
	Stored at 32°	Stored in room	Stored at 32°	Stored in room	Stored at 32°	Stored in room	Stored at 32°	Stored in room
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Beet	86.5	82.5	76.2	76.2	89.9	86.3	89.9	88.7
Cabbage	88.2	84.2	70.2	68.7	90.4	90.0	90.1	89.5
Carrot	87.7	75.8	79.8	56.2	88.3	88.4	88.2	89.2
Onion	48.0	8.2	6.6	.1	77.7	62.4	80.7	65.8
Spinach	63.5	53.8	39.2	29.1	69.6	66.1	67.9	66.3
Tomato	86.4	85.5	82.1	81.2	91.6	88.8	89.9	88.7

Seed	Previous storage humidity 66 percent				Previous storage humidity 51 percent			
	86 days at 80°		87 days at 50°		56 days at 80°		80 days at 50°	
	Stored at 32°	Stored in room	Stored at 32°	Stored in room	Stored at 32°	Stored in room	Stored at 32°	Stored in room
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Beet	87.9	86.9	88.2	86.1	89.0	87.7	88.6	88.2
Cabbage	91.8	89.3	92.3	91.1	92.9	89.4	90.7	90.1
Carrot	89.7	89.7	89.8	88.2	89.0	88.7	89.8	89.5
Onion	73.2	59.4	83.2	76.7	84.3	74.3	81.8	77.7
Spinach	68.3	63.9	76.6	74.7	75.8	75.0	73.8	73.3
Tomato	87.5	87.0	92.8	91.8	94.0	90.3	93.5	92.2

[1] Minimum differences required for significance between 32° and room storage are for the several kinds of seeds: Beet, cabbage, and carrot, 3.0; onion and spinach, 4.0; tomato, 2.5 percent.

The germination results on the seeds from storage at 32° F. were entirely comparable with those on the duplicate samples germinated at the time the seeds were placed at 32°, as shown by table 12. The loss of viability among the samples stored in the laboratory differed greatly, depending on the kind of seed and also on the previous treatment of the seed. Tomato and beet, which were very resistant to deterioration in the humidity chambers and in the warehouse, showed no consistent significant decrease in viability while stored either in the laboratory or at 32°. On the other hand, onion, the most unstable of the seeds considered in the table, showed highly significant differences between the laboratory-stored and the 32° lots, for all previous treatments. Deterioration of onion at room temperature occurred whether or not previous treatment had resulted in any evidence of injury at the time the seeds were stored in the laboratory.

Cabbage, carrot, and spinach were intermediate in their susceptibility to deterioration in the humidity chambers and in the warehouse, and likewise were intermediate in deterioration in the laboratory after previous treatment. They showed some marked differences between the room-stored and the 32°-stored lots, but only for those seeds that had been previously held at high humidity and high temperature.

The data in table 34 are derived from the figures for different dehydration treatments. In no instance was there a significant difference between the nondried and the dried seeds in deterioration at room temperature. This suggested that initial differences in moisture content did not long persist in the small packets under laboratory conditions.

It will be noted that in cabbage and carrot the differences between cold storage and laboratory storage are much greater for the 55-day than for the 24-day lots from high humidity and high temperature, although the seeds of the 55-day lot were in the laboratory for the shorter time. In these instances and possibly others it appears that the damage under laboratory conditions resulted not so much from the interaction of laboratory temperature and time with seed moisture as with the incipient deterioration developed during previous storage. The progress of this deterioration was held in check by storage at 32° F., but continued during laboratory storage.

DEHYDRATED SEEDS RETURNED TO HUMIDITY CHAMBERS

After the several kinds of seeds from each of the humidity chambers had been dried and samples taken, quantities ranging from a few hundred grams to nearly a kilogram of each remained. These were returned to the original condition of storage, where they remained until early March, a total storage period of 251 to 266 days, when they were again removed, weighed to determine change in weight, and samples drawn for determination of moisture content and viability.

The moisture content of these seeds that had been dried had all reached levels already shown to be characteristic for each kind at each storage condition. The figures were practically identical with those for the 251-day samples shown in tables 13 to 15, 19, 20, and 23 to 26.

Table 35 shows the results of the germination tests on these seeds. Because of the large number of samples, the seeds from the 150° and 120° F. drying treatments had to be germinated in successive series 12 days apart. Germination conditions were apparently very uniform throughout, since there was no significant difference between the two series. The data from the 150° and the 120° treatments were therefore combined to give the figures for the "dried" arrays in table 35. The figures for "none" in the table are from the 251-day samples, germinated within 2 weeks of the same time, and are included for comparison.

TABLE 35.—*Effect of artificial drying and return to the storage chamber, on viability of seeds stored under different conditions for 8½ months* [1]

Seed	Drying treatment	Germination of seeds from storage at [2]—						Mean germination
		Temperature 80° F.			Temperature 50° F.			
		Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 68 percent	Humidity 51 percent	
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lima bean	None	26.5	61.0	47.0	61.0	69.0	58.0	53.7
	Dried	5.0	59.3	50.3	59.9	62.5	63.3	50.2
Kidney bean	None	0	86.5	92.0	90.5	79.0	77.5	70.9
	Dried	0	87.3	84.5	88.4	86.5	90.0	72.8
Sweet corn	None	0	66.0	70.0	57.0	59.5	69.0	53.6
	Dried	0	59.3	60.5	51.9	66.8	68.5	51.1
Beet	None	8.8	78.8	87.8	86.5	81.3	85.0	71.4
	Dried	4.6	83.5	88.5	85.4	88.4	85.3	72.6
Cabbage	None	.8	89.3	91.0	88.2	91.6	92.3	75.5
	Dried	.3	89.3	91.3	89.4	92.4	92.8	75.9
Carrot	None	1.0	86.6	89.8	87.8	87.6	90.8	73.9
	Dried	.3	89.6	90.0	89.4	89.1	89.1	74.0
Onion	None	.1	37.4	72.0	64.3	76.0	74.5	54.2
	Dried	0	36.1	70.5	65.7	80.5	81.4	57.2
Spinach	None	.3	63.3	75.0	63.2	71.3	72.8	57.6
	Dried	0	57.5	71.1	55.4	70.9	73.5	54.8
Tomato	None	68.1	85.0	91.8	86.6	90.5	91.4	85.6
	Dried	66.7	81.6	93.3	85.2	91.1	92.3	85.0

[1] Nondried samples were the small lots removed at 251 days. Dried samples were from bags removed at about 260 days.
[2] Minimum differences required for significance between values are approximately 5 percent.

The results in table 35 show that the different kinds of seeds deteriorated about the same over a period of 251 to 266 days when they had been removed and dried 2 to 4 percent and returned to the original condition at 24 to 87 days as when they remained continuously in the given storage condition. Lima bean from the high-humidity high-temperature chamber and sweet corn from the low-humidity high-temperature chamber showed a marked decrease of viability after drying, but, as shown in table 31, both these seeds from these storage conditions had shown injury when tested immediately after drying.

It is probable that the comparatively small amount of moisture removed by drying was regained quickly on return of the seeds to the

TABLE 36.—*Analysis of variance of data for table 35*

Source of variation	Data for beans and sweet corn		Data for small seeds	
	Degrees of *freedom*	Mean *square*	Degrees of *freedom*	Mean *square*
Total	95	1,018.1	383	1,191.6
Between storage lots	7	[1] 11,633.8	7	[1] 50,110.7
Between drying temperatures	1	12.8	1	0+
Between species	2	[1] 4,414.4	5	[1] 10,313.4
Storage × drying	7	[2] 37.4	7	[2] 32.2
Storage × species	14	[1] 344.0	35	[1] 1,407.0
Drying × species	2	[1] 75.8	5	[1] 68.8
Storage × drying × species	14	24.4	35	[2] 21.2
Remainder (error)	48	13.7	288	12.0

[1] Significant with reference to error by odds of more than 100 to 1.
[2] Significant with reference to error by odds of more than 19 to 1 but less than 100 to 1.

humidity chambers, so that one could hardly expect to observe a difference in viability after the period of 5 to 7½ months involved.

It would appear that a beneficial effect from drying seeds can be obtained only if the seeds can be kept dry subsequently.

A detailed variance analysis of results on these dried seeds is presented in table 36.

DISCUSSION

This experiment was planned to show the effect of different humidities of the air and different temperatures on the moisture content of seeds and on their rate of deterioration over short periods. Although the control of humidity was not so close as had been anticipated, the results do show the moisture content attained by seeds within the recorded range of humidity and the changes in germination as related to the moisture content.

It may be assumed that, at a given temperature, the moisture content of the seed determines its longevity. However, the moisture content of the seed depends on the humidity of the surrounding air; therefore it is very important to know the amount of change to be expected in the moisture content of different kinds of seeds exposed to air of different relative humidities. Examination of table 6 and figure 2 shows clearly that the different kinds of seeds attained different moisture contents at a given humidity of the air and also that the rate of change with increase of humidity was very different. Peanut had the lowest moisture content for a given humidity of any kind of seed tested, and the rate of change in moisture content with increasing humidity was the least. Kidney bean changed the most in moisture content with increasing humidity and also reached the highest moisture content at high humidity. Cabbage and tomato showed a rate of change of moisture content with humidity only slightly greater than peanut, but at any given humidity the moisture content was higher.

In this experiment, for any one species there was a reasonably uniform rate of change of moisture content over the range of humidities tested. Coleman and Fellows (*6*) and Humphries and Hurst (*11*) found a rapid increase in the rate of moisture content as the relative humidity approached 100 percent. However, their results for the range of humidities used in the present experiment (roughly 44 to 80 percent) are very similar to those reported here.

When seed was exposed freely to the air, as in this experiment, its moisture content changed very rapidly with changes in humidity of the air. In bulk storage the rate of change will undoubtedly depend largely on the rate of movement of air through the bulk of seeds. However, the ultimate moisture content attained at any certain humidity will probably be as shown in the tables and figures. This is further indicated by the moisture contents of the seeds in bags when removed for dehydration; the moisture content of these seeds in 2-kg. lots was very similar to samples in small cans under the same conditions.

The deterioration of any one kind of seed at one temperature was, in general, proportional to the humidity of storage or to the moisture content of the seed. However, the different kinds of seeds responded very differently to any specific humidity level or moisture content of the seed and to temperature of storage.

The total time of storage in this experiment was too short for deterioration to appear under all conditions, but the results show the comparative behavior of different kinds of seeds and the ranges of moisture and temperature that are unfavorable for safe storage of seeds for short periods.

Tomato was the most tolerant of high humidity and high temperature of the kinds tested, and beet was next. Tomato showed a small but significant loss in a comparatively short time, while beet showed no significant loss until 110 days but fell in germination rapidly thereafter and was much lower in germination than tomato at 251 days. Since the beet ball contains much spongy inert matter surrounding the true seeds, the actual moisture changes in the seed itself are not known.

Carrot also was comparatively resistant, considering the moisture content of the seed; but here again there is no knowledge of the moisture changes in the small, active embryo, which is enclosed by the horny reserve material.

The two kinds of bean showed comparatively little loss of germination, considering the high moisture content attained at high relative humidity.

Cabbage was comparatively resistant. Although at 110 days the loss of germination of spinach was greater than that of cabbage or tomato for comparable humidities, for comparable moisture content of the seed the loss was similar.

Onion was very sensitive to high humidity and high temperature, which may be related to the higher moisture content of the onion seed than of cabbage or tomato. On the other hand, the loss of germination of peanut was comparable to that of onion for a given humidity and temperature, although the moisture content of the seed was much lower. Sweet corn showed a serious loss of germination at high humidity and high temperature, even though the moisture content of approximately 13 percent is not usually considered too high for safe storage of this kind of seed at lower temperature.

In approximately 4½ months between the 110-day and 251-day tests all kinds of seeds deteriorated markedly in storage at 78 percent humidity and at 80° F. Only tomato retained even a fair germination, but the rate of germination and the vigor of seedlings was much reduced. Under the other controlled conditions losses during this period were not marked and were significant only for onion and peanut at 66 percent humidity at 80° F. and for peanut at 78 percent humidity at 50°.

The germination of seeds stored in bags for dehydration studies was quite comparable to those stored in small cans for comparable periods.

The close agreement of tests conducted as the seeds were removed from the storage treatments with tests on the same samples held at 32° F., several months after removal from the treatments, indicates that deterioration can be not only prevented but stopped by low temperatures. In the comparable samples held in small bulks in the comparatively dry air of the laboratory, deterioration was evident only in those samples that had been weakened by the previous storage conditions.

It is evident that the germination response of different kinds of seeds at a given humidity and temperature depends on both the seed's moisture content and its inherent nature. The moisture content of the active tissues of the growing regions and their chemical composition should be considered rather than the moisture and composition of the entire seed.

Duvel (*8*) has shown results rather similar to those for cabbage, onion, tomato, and sweet corn, and the actual losses for comparable moisture content and temperature were similar.

Barton (*2*) worked on carrot, onion, and tomato, included in the present study, together with other vegetable seeds. Seeds that had maintained a high viability after 6 years' storage under dry conditions fell markedly in germination when removed to chambers with 93 percent humidity at 25° C. and 35° for 2 weeks to 3 months. Also, onion seed stored over saturated salt solutions calculated to give a series of relative humidities was practically dead after 1 month at 90 percent humidity and 25° C. and after 3 months at 70 percent humidity at the same temperature. When stored at 50 percent humidity there was no significant loss in 3 months at either 25° or 30°.

Beattie and associates (*4*) did not find a definite effect of temperature of storage on viability of peanut, but their highest temperature was 70° F. Although they did not determine the moisture content, it is probable that it was lower than would be expected to show deterioration at 70°. It should be noted that in the present experiment the peanuts were shelled. Beattie and associates found that peanuts kept better unshelled than shelled.

Most of the kinds of seeds used in this experiment showed a significant fall in germination in 1 month or less when stored at 80° F. and at approximately 80 percent relative humidity, conditions that are not at all unusual in summer and early fall in the coastal growing sections. However, at the same temperature, but at a low humidity where the moisture was maintained at 8 percent or less, most kinds of seeds did not fall seriously in germination in the first 110 days of the experiment, and only lima bean, onion, and peanut in 251 days. Also, even at high humidity, there usually was no serious loss if storage was at 50°. It would seem, then, that the serious losses that often occur from rapid loss of germination can be obviated either by drying the seeds and keeping them dry or by holding them at a low temperature.

If cold storage is used, it must be remembered that seeds having a high moisture content will deteriorate in a comparatively few days when removed from cold storage to high summer temperatures, and that if the relative humidity of the cold-storage room is high, the seeds will develop just as high or a higher moisture content than at an equal relative humidity at a higher temperature.

At high humidity (mean 78 percent) and high temperature (80° F.) a significant loss of germination was found in 10 days for cabbage and onion; in 20 days for sweet corn, spinach, tomato, and peanut; in 30 days for carrot; in 40 days for kidney bean; in 80 days for lima bean. Beet was the only kind that did not lose significantly in germination over the 110-day period; however, it was practically all dead at 251 days.

SUMMARY AND CONCLUSIONS

Ten kinds of vegetable seeds—lima bean, kidney bean, sweet corn, peanut (shelled), beet, spinach, cabbage, carrot, onion, and tomato—were stored in small containers at 80° and 50° F. and at three different humidities at each temperature, approximately 44 and 51 percent, 66 percent, and 78 and 81 percent. Moisture determinations and germination tests were made at 10-day intervals. At various times during the experiment, seed was removed and dried rapidly at approximately 150° and 120°, and moisture determinations and germination tests were made.

It was found difficult to control the high and low humidities as closely as desired.

The moisture content of the seeds reached equilibrium in about 20 days for the smaller seeds and in 20 to 40 days for the larger seeds. The mean moisture content of the seeds stored at high humidity varied from about 8 percent for peanut to 15 percent or above for lima bean, kidney bean, and beet. At low humidity the mean moisture content at both temperatures varied from approximately 5 percent for peanut to approximately 10 percent for lima bean.

The mean moisture content of the seeds was correlated more closely with the air condition expressed as relative humidity than with any other method of expression.

There was a tendency for a higher moisture content at a given relative humidity at 50° than at 80° F., and this difference was statistically significant for spinach, kidney bean, carrot, tomato, and sweet corn.

At high humidity and high temperature at the end of 110 days, the germination of onion and peanut had fallen to zero, of spinach and sweet corn to 25 percent or less. Of the others, only beet and tomato maintained a germination of above 70 percent. At 251 days, lima bean germinated 26 percent, beet 9 percent, and tomato 68 percent. All others were zero to 1 percent.

At low humidity (51 percent) and low temperature (50° F.), only kidney bean and sweet corn had fallen significantly in germination by the end of 251 days.

In warehouse storage, deterioration was, in general, comparable with that at 66 percent relative humidity at 80° F., although in some cases, notably onion, the fall in germination was even more rapid in the warehouse.

Among different kinds of seed, the deterioration at high temperature was not always correlated with the relative moisture-absorbing capacity of the seeds.

Seeds from the several storage conditions described were removed and germinated at intervals of 10 to 110 days, and portions were stored at 32° F. and 60 percent humidity. Upon germination of the latter 6 to 9 months later, no deterioration at 32° storage could be definitely detected.

The moisture content could be reduced 4 to 5 percent by heating the seed from the high-humidity chambers in moving air at temperatures of 120° and 150° F. The time required varied from one-half hour for the smaller seeds to 3 hours for the beans.

Dehydration of the larger seeds for approximately 3 hours at 150° F. damaged viability, especially if the seeds had been injured by previous storage conditions. Peanut was especially susceptible to injury by heating. The smaller seeds, dried for shorter periods, showed no injury as a result of heating.

Seeds from the dehydration studies were stored in the laboratory as well as at 32° F. When germinated after 6 to 8 months in the laboratory, onion showed marked loss of germination following all previous storage conditions; cabbage, carrot, and spinach showed serious loss only following previous storage at high humidity and high temperature; beet and tomato did not show significant loss in the laboratory following any previous storage condition.

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ADDENDUM

At the time this bulletin was written (May 1939) there remained residues from the bag storage of seed that had been dehydrated and returned to the original storage condition and also undried seed from the medium and low humidities. In warehouse storage there remained only undried seed in bags. After 426 days' storage these seeds were tested for germination (while this bulletin was in press). The results are summarized in table 37.

TABLE 37.—*Effect of storage for 426 days under different conditions on viability of seeds*

Seed	Germination of seeds stored at conditions shown [1]							Approximate minimum difference for significance (except warehouse)[2]
	Temperature 80° F.			Temperature 50° F.			Warehouse	
	Humidity 78 percent	Humidity 66 percent	Humidity 44 percent	Humidity 81 percent	Humidity 66 percent	Humidity 51 percent		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lima bean	0	69.3	70.2	64.9	70.3	69.2	72.3	5.5
Kidney bean	0	88.9	92.1	90.0	92.4	92.3	88.0	3.5
Sweet corn	0	65.0	79.2	64.1	80.5	81.8	63.3	4.0
Peanut		52.8	67.0		83.8	84.3	11.0	12.0
Beet	0	87.7	90.8	86.1	90.2	90.8	84.5	4.0
Cabbage	0	88.0	92.2	88.0	91.8	92.2	79.5	2.5
Carrot	0	87.7	90.8	86.1	90.2	90.8	84.5	2.5
Onion	0	5.8	74.1	48.2	75.1	80.2	1.8	4.5
Spinach	0	56.7	70.8	47.1	70.7	74.0	21.0	4.0
Tomato	1.2	81.3	90.1	62.0	90.5	92.7	80.0	3.0

[1] See text for details of treatment of samples.
[2] Since the values for warehouse storage are based on smaller numbers, approximately 50-percent larger difference is required for significance in comparing these values with those for the other conditions (except peanut, where all values are based on 400 seeds).

Because there was no significant difference between germination of the seed dried at the two temperatures and returned to the original storage condition and the seed that had not been dried, the results from these three drying treatments were combined for each storage condition. For peanut, only undried seed was available. The germination percentages given in the table are based, for all warehouse storage, on 400 seeds; for peanut at all conditions, on 400 seeds; for beans, except warehouse, on 800 seeds; for seeds at high humidity, on 1,600 seeds; for all other kinds and conditions, on 1,200 seeds.

The results in table 37 should be studied in comparison with tables 35 and 28. At 80° F. and 78 percent humidity, all kinds of seed except lima bean and tomato were practically dead at 251 days; at 426 days there was no sign of life in any kind except tomato, and this seed was of no value. At the other controlled conditions there was no definite fall of germination between 251 and 426 days, except for onion and spinach at medium humidity, high temperature, and at high humidity, low temperature, and a slight fall for tomato at these same conditions. Under warehouse storage, peanut, onion, and spinach fell appreciably in germination between 251 and 426 days' storage.

The results of these later tests do not change, but give additional emphasis to, the conclusions of this bulletin.

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U. S. GOVERNMENT PRINTING OFFICE: 1940

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents

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