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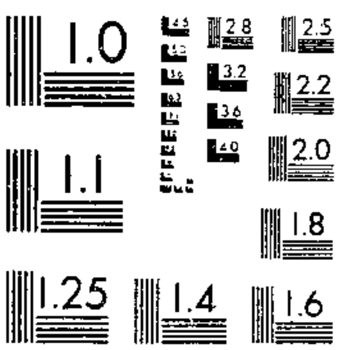

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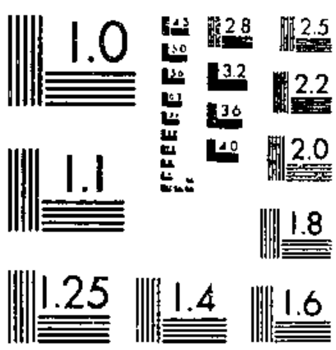

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DORMANCY IN LETTUCE SEED AND SOME FACTORS INFLUENCING ITS GERMINATION[1]

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CONTENTS

INTRODUCTION

The seed of some varieties of lettuce are known to germinate poorly under conditions generally considered to be satisfactory for lettuce. Seed of different varieties and different lots of seed of the same variety differ greatly in their ability to germinate at temperatures above 20° C. It has been pointed out by Thompson (*11*)[2] that the variety Hubbard Market consistently produces some seed very difficult to germinate at high temperatures and that the variety Iceberg seldom produces seed adversely sensitive to temperatures as high as 20° to 30°. These two varieties appear to represent extremes in respect to the response to temperature of the seed during germination. Other varieties behave in a manner somewhere between these two.

Thompson has observed that the variety Iceberg, which seldom produces dormant seed, is a very low yielder of seed as compared with the varieties Hubbard Market and Grand Rapids, which consistently produce dormant seed.

For want of a better term, seed that will not germinate in darkness at a constant temperature of 25° C. without some special treatment are referred to throughout this discussion as dormant. Since the germination of such seed is benefited by exposure to certain light rays while moist, it has been suggested (*3*) that they be designated as "light-sensitive." It will be shown later that temperature is perhaps a more important factor than light in breaking this dormant condition. The term "temperature-sensitive" would perhaps be more generally applicable than light-sensitive as applied to such seed. Since the germination of such seed depends on the control of a number of factors,

[1] Submitted for publication April 5, 1938.
[2] Italic numbers in parentheses refer to Literature Cited, p 20.

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including temperature, light, aeration, moisture, and other environmental factors, the general term "dormancy" seems the most satisfactory.

In some cases wherein dormancy is not difficult to break, it may disappear after a few weeks or months in storage at room temperatures to the extent that satisfactory germination may result. It will be shown later that in some lots of seed this dormant condition may continue to some extent for very long periods of storage.

If such seed is to be planted soon after harvest the percentage of germination may be very low unless the seed is given some special treatment to break the dormant condition.

The question arises as to how such seed can be treated to insure satisfactory germination where it is necessary to plant lettuce seed when the soil and air temperatures are high. A number of investigators have studied this problem from the viewpoint of devising methods of treating dormant seed to make it germinate.

Larson, Gilbert, and Ure (*7*) advise soaking the seed in water for 6 hours and then exposing it to diffused light at 23° C. They were among the first to recognize the beneficial influence of light in the germination of lettuce seed.

Davis (*2*) found absorbent cotton to be a better medium than blotting paper for the germination of lettuce seed. The advantage of the cotton was attributed to the better aeration afforded.

Hopkins (*6*) found that presoaking the seed in water at 20° C. for 2 hours previous to testing was the best method of inducing germination. Borthwick and Robbins (*1*) recommended prechilling of moist seed for 5 days at a temperature around 4° C. Shuck (*8*) concluded that exposure of moist seed to light at a temperature of 15° to 18° provides the best condition for germination of lettuce seed of all ages.

Flint (*3*) found the longer wave lengths of the visible spectrum—red, orange, and yellow—most effective in promoting germination. Flint and McAlister (*4*) reported that light rays in the region of 7,600 angstrom units and in the region between 4,200 and 5,200 A. have an inhibiting effect on germination of some lettuce seed. Flint and McAlister (*5*) presented evidence to show that the critical wave length for the promotion of lettuce seed is approximately 6,700 A.

Thornton (*12*) reported that dormant lettuce seed may be made to germinate in both light and darkness at a temperature of 35° C. in an atmosphere containing from 40 to 80 percent of carbon dioxide.

Most of the investigations so far reported have dealt with treatments intended for laboratory seed-testing practices where the seed is germinated immediately following the treatment or treated during the germination period.

Borthwick and Robbins (*1*) found that seed which had been held in a moist condition at 4° C. for 6 days would give a fairly high percentage of germination when planted in soil having a maximum temperature of 30° or above for 6 to 7 hours during the warmest part of the day. Seed not so treated germinated very poorly.

The results reported by Shuck (*9*) show that moist seed exposed to light may, under certain conditions, give a high percentage of germination after being dried. However, he observed wide variation in this response among different lots of light-treated seed. The writer has found that promiscuous soaking of lettuce seed, exposing it to the light and then drying, is a very uncertain means of inducing germina-

tion following drying. It was observed that such a procedure neglected some important factors then unknown and that careful control of certain factors must be observed before the method could be used as a practical treatment for seed to be planted at some later date.

The investigations herein reported were made for the purpose of developing and standardizing a method of seed treatment that would increase germination of dormant lettuce seed which had been dried following the treatment, thus permitting its use in practical field planting. Prompt and complete germination of freshly harvested lots of seed is of particular importance in breeding and genetic studies being conducted by the writer. No attempt has been made here to develop methods intended for laboratory seed testing where the treatment is given during germination or where the seed is immediately transferred to the germinating medium after treatment and while still moist.

The percentage germination figures shown in the tables are means of quadruplicate determinations. The magnitudes of differences between treatments required for significance were calculated as twice the standard error of the difference between means; this latter was derived from the remainder error obtained by analysis of variance.

A seed treatment to be applicable for field culture must permit drying of the seed sufficiently to allow handling in a mechanical seeder without injury.

EXPERIMENTAL RESULTS

RELATION OF AGE OF SEED TO DORMANCY

It is generally believed that dormancy in lettuce seed is a condition that is corrected by a short period of storage at room temperature. This holds true for some lots of lettuce seed showing dormancy immediately after harvest. The studies made in these investigations show that dormancy exists in different degrees in different lots of seed. This may vary from only slightly dormant seed that will reach almost 100-percent germination after a short period of storage to very dormant seed that may germinate not over 50 percent after 18 months in storage, if germination is carried out in darkness at temperatures above 25° C.

Seed from five lettuce plants of the variety Hubbard Market was tested for germination in darkness at 25° C. 2 weeks after harvest in August 1935. At that time the seed from each of the five plants was 100-percent dormant. A similar test was made on these same lots of seed in February 1937, 18 months after harvest, and they were still about 50-percent dormant when germinated in darkness at 25°. That the seed was still viable was shown by the high percentage of germination obtained under the same conditions following treatment for the breaking of dormancy. In treating, the seed was soaked in tap water for 2 hours at 10°, exposed to diffused light on damp muslin for 2 hours at 20°, then slowly dried on damp muslin in an icebox at 10°. The results of these tests are given in table 1.

It is doubtful whether seed as dormant as these lots of Hubbard Market will come out of dormancy entirely in storage before the seed begins to lose its viability from age. Numerous other lots of Hubbard Market and Grand Rapids lettuce seed have shown a high percentage of dormancy after long periods in storage.

TABLE 1.—*Effect of treatment on germination of Hubbard Market lettuce seed 18 months old*

Treatment and plant No.	Seeds germinating [1]		Treatment and plant No.	Seeds germinating [1]	
	Number	Percent		Number	Percent
Untreated:			Treated:[2]		
1	25	50.0	1	48	96.0
2	26	52.0	2	50	100
3	29	58.0	3	47	94.0
4	23	46.0	4	43	86.0
5	20	40.0	5	49	98.0
Average		49.2	Average		94.8

[1] After 72 hours in darkness at 25° C. (50 seeds).
[2] Soaked 2 hours in water at 10° C. Exposed to diffused light 2 hours, then dried slowly at 10°.

INFLUENCE OF LIGHT AND TEMPERATURE ON THE GERMINATION OF DORMANT LETTUCE SEED

The tests in the studies on influence of light and temperature on germination were made on samples from a single lot of seed (approximately one-quarter of a pound), which was harvested from 10 plants of the variety Grand Rapids. After harvesting and cleaning, the seed was thoroughly mixed, and the tests were made at three different temperatures in darkness. Each test sample consisted of 100 seeds. Similar lots of 100 seeds each of the variety Iceberg were germinated under the same conditions. Seed of this variety was used to determine the comparative response of dormant and nondormant lettuce seed at the three temperatures. Since it was known that the seed of Iceberg will generally germinate at a higher temperature than most varieties, it was thought that the relative response of the seed of these two varieties would indicate the degree of dormancy of the Grand Rapids seed used in the tests.

The seed of the two varieties was germinated on wet muslin in 95-mm Petri dishes. Germination was carried out in a commercial seed germinator in darkness at 10°, 25°, and 30° C. The counts were made at the end of 96 hours. The results of these comparative tests are given in table 2.

TABLE 2.—*Effect of temperature on germination of dormant Grand Rapids and nondormant Iceberg lettuce seed after 96 hours in darkness*

Variety	Germination of 100 seeds at—			Variety	Germination of 100 seed at—		
	10° C.	25° C.	30° C.		10° C.	25° C.	30° C.
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
Iceberg	100	100	90	Grand Rapids	25	3	0
Do	100	98	95	Do	14	5	0
Do	100	100	87	Do	12	2	0
Do	100	100	91	Do	17	4	0
Average	100	99.50	90.75	Average	17	3.50	0

These results indicated that the Grand Rapids seed was highly dormant and satisfactory material for study. This lot of Grand Rapids seed was then used in conducting the following series of tests to show the influence of light and temperature on the germination.

Before these tests were made, however, the treated samples were thoroughly dried and stored for a period of 2 to 3 weeks.

SERIES 1

Series 1 consisted of 10 samples of dormant Grand Rapids seed, including an untreated check. The treated lots were held in water in darkness at 5° C. for periods of from 1 to 72 hours. After the preliminary soaking, each sample was exposed to diffused light several hours and dried at temperatures of 25° or 35°. The results of the germination tests are given in table 3. Germination was stimulated by all of the treatments except Nos. 1 and 9, which were dried rapidly following the preliminary soaking. While most of the treatments had a significant stimulating effect on germination, the percentage was very low. Sample No. 3 gave the highest germination, with 44 percent. Samples Nos. 3, 5, and 7, which were exposed to diffused light while drying at 25°, germinated better than the lots that were dried at 35°.

TABLE 3.—*Germination of Grand Rapids lettuce seed (series 1) held in water in darkness at 5° C. for various lengths of time and dried in diffused light at high temperature*

Sample No.	Time of soaking	Treatment following soaking			Seed germinated after 72 hours in darkness at 25° C.[1]
		Drying medium	Rate of drying	Temperature during drying	
	Hours			*° C.*	*Percent*
1	1	Dry filter paper	Rapid	35	7.0
2	2	Damp muslin	Slow	35	22.0
3	4	do	do	25	44.0
4	4	do	do	35	31.0
5	24	do	do	25	40.0
6	24	do	do	35	35.0
7	72	do	do	25	39.0
8	72	do	do	35	32.0
9	72	Dry filter paper	Rapid	35	5.0
Untreated check					3.5

[1] A percentage difference of 7.54 is required to show significance between treatments.

SERIES 2

Seven samples, including a check, were tested in series 2. The treated samples were held on wet muslin in darkness at 5° C. for from 3 to 7 days. Previous to drying, these samples were held moist at about 4° for a few days, similar to the manner reported by Borthwick and Robbins (*1*) to be effective in inducing germination of dormant lettuce seed. The samples were treated differently during drying. The results are given in table 4.

The exposure of samples Nos. 5 and 6 to light at temperatures of 27° and 30° C. did not increase the germination above that of samples 1 and 2, which were not exposed to light. While all of the treatments resulted in a very great increase in germination over the untreated check, samples Nos. 3 and 4, which were dried at 10° without light exposure, alone could be considered satisfactory. Dried at 10° they gave a significant increase in germination over samples Nos. 1 and 2 held at 5° until dry.

TABLE 4.—*Germination of Grand Rapids lettuce seed (series 2) held on wet muslin in darkness at 5° C. for 3 to 7 days, then dried under various conditions of light and temperature*

Sample No.	Time on wet muslin at 5° C.	Conditions during drying	Seed germinated after 72 hours in darkness at 25° C.[1]
	Days		*Percent*
1	3	Dried in darkness at 5° without light exposure	62.0
2	5	do	75.0
3	5	Dried in darkness at 10° without light exposure	93.0
4	7	do	91.5
5	5	Dried on damp muslin in diffused light at 27°	68.0
6	7	Dried on damp muslin in diffused light at 30°	49.5
Untreated check			4.0

[1] A percentage difference of 4.86 is required to show significance between treatments.

SERIES 3

Ten lots of seed, including a check sample, were included in series 3. The treated lots were soaked in tap water in darkness at 5° C. for from 1 hour to 8 days. Following the soaking in water, each lot was given different light and temperature treatments. However, all lots were dried at relatively low temperatures as compared with those in series 1. The results from series 3 are presented in table 5. A high percentage of germination resulted from all of the treatments. Soaking for as long as 8 days did not reduce the effectiveness of the postsoaking treatments.

TABLE 5.—*Germination of Grand Rapids lettuce seed (series 3) held in tap water in darkness at 5° C. for various lengths of time, then exposed to diffused light and dried at low temperatures*

Sample No.	Time of soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Hours		*Percent*
1	1	Exposed to diffused light on damp muslin at 22° for 5 minutes; dried slowly on damp muslin in dark at 10°.	97.0
2	2	Exposed to diffused light on damp muslin at 18° for 10 minutes; dried slowly on damp muslin in dark at 10°.	98.0
3	3	Exposed to diffused light on damp muslin at 22° for 2½ hours; dried slowly on damp muslin in dark at 10°.	96.0
4	4	Exposed to diffused light on damp muslin at 25° for 2 hours; dried slowly on damp muslin in dark at 10°.	89.0
5	24	Dried slowly on damp muslin in diffused light at 18°	91.0
6	24	Exposed to diffused light on damp muslin at 22° for 15 minutes; dried slowly on damp muslin in dark at 10°.	97.0
7	72	Dried slowly on damp muslin in diffused light at 16°	97.0
8	72	Exposed to diffused light on damp muslin at 16° for 10 minutes; dried slowly on damp muslin in dark at 10°.	99.0
9	192	Exposed to diffused light on damp muslin at 16° for 15 minutes; dried slowly on damp muslin in dark at 10°.	98.0
10 (untreated check)			5.5

[1] A percentage difference of 3.48 is required to show significance between treatments.

The germination percentages in series 3 are in striking contrast with those obtained in series 1. Exposure to light and drying at temperatures above 25° C. were much less effective in promoting germination than exposure and drying at lower temperatures. All of the samples were stored for 2 weeks following treatment and before testing.

SERIES 4

Series 4 comprised eight samples that were presoaked in tap water in darkness at 10° C. for periods of 2, 4, and 24 hours. After being soaked, the seed was removed from the water and each sample was given a different treatment as to temperature, exposure to light, and rate of drying. All of the treated samples were then stored for 2 weeks at room temperature before making the germination tests. The results from series 4 are given in table 6.

TABLE 6.—*Germination of dormant Grand Rapids lettuce seed (series 4) held in water in darkness at 10° C., then given various treatments*

Sample No.	Time of soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Hours		*Percent*
1	2	Seed held on wet muslin in the dark at 20° for 5 hours; dried slowly in the dark on damp muslin at 10°.	97.5
2	2	Seed held on wet muslin in diffused light at 20° for 3½ hours; dried slowly in diffused light at 20°.	98.0
3	2	Seed held on wet muslin in diffused light at 20° for 3½ hours; dried slowly in diffused red light at 20°.	96.0
4	4	Seed held on damp muslin in the dark at 10° for 17 hours; dried slowly in diffused light at 20°.	99.5
5	24	Dried slowly in the dark at 10°	94.0
6	24	Dried rapidly in diffused light at 30°	21.0
7	24	Seed held on damp muslin in the dark at 10° for 24 hours; dried slowly in the dark at 20°.	98.0
8	24	Dried slowly in diffused light at 20°	97.0

[1] A percentage difference of 5.26 is required to show significance between treatments.

All but one sample, No. 6, gave a high percentage of germination. The low percentage in this case is attributed to the rapid drying at 30° C. It is assumed that this rapid drying, or the high temperature at which the seed was dried, or both, prevented breaking of dormancy or induced a return to the dormant condition. The high percentage of germination of samples Nos. 1 and 5, which were never exposed to light, indicates that temperature is an important factor in the germination of such seed.

SERIES 5

The germination data from series 5, which consisted of eight samples including an untreated check, are given in table 7. In this series the seed was presoaked in tap water in darkness for 4 days at 10° C. Following the soaking, each sample was given a different treatment, as in the previous series. The check lots averaged 4-percent germination. All of the treatments resulted in very marked increase in germination.

In samples Nos. 2, 3, and 4, which were exposed to light and dried at temperatures below 30° following the soaking, there was very high germination. Sample No. 1, which was dried rapidly at 25°, and samples Nos. 5, 6, and 7, which were dried at 30°, gave much lower percentages than Nos. 2, 3, and 4. The rapid drying of sample No. 1 and the high temperature at which Nos. 5, 6, and 7 were exposed to light and dried appear to have reduced the percentage as compared with slower drying at lower temperatures.

TABLE 7.—*Germination of dormant Grand Rapids lettuce seed (series 5) presoaked in water in darkness at 10° C. for 4 days*

Sample No.	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
		Percent
1	Dried rapidly in diffused light at 25°	81.0
2	Seed held on wet paper in diffused light at 25° for 1 hour; dried slowly in diffused light at 25°.	95.0
3	Seed held on wet paper in bright sunlight for 1 hour; dried slowly in diffused light at 25°.	96.5
4	Seed held on wet paper in diffused light at 27° for 1 hour; dried slowly in diffused light at 27°.	94.0
5	Seed held on wet paper in full sunlight at 30° for 1 hour; dried slowly in diffused light at 30°.	87.0
6	Seed held on wet paper in bright sunlight for 10 minutes at 30°; dried slowly in diffused light at 30°.	87.5
7	Seed held on wet muslin in diffused light at 30° for 3 hours; dried slowly in diffused light at 30°.	82.0
8 (untreated check)		4.0

[1] A percentage difference of 6.10 is required to show significance between treatments.

Soaking as long as 4 days did not reduce the effectiveness of the postsoaking treatments where the exposure to light was at a temperature below 30° C. and the drying not too rapid.

SERIES 6

Series 6 consisted of six samples presoaked in tap water in darkness at 30° C. for 2 and 4 hours. As in the previous series, each sample was treated differently following soaking. The results of series 6 are presented in table 8. Only one sample, No. 6, gave good germination. This sample was exposed to light for 5 minutes at 20° and dried slowly on damp muslin in darkness at 10°. The poor germination of most of the samples in this series indicates the injurious effect of soaking and drying at high temperature. Sample No. 4, which was exposed to diffused light for 24 hours at 32°, gave only 1-percent germination. The high temperature and the poor aeration resulting from the saturated atmosphere in this case apparently prevented the breaking of dormancy. The injurious effect of rapid drying at high temperature is indicated by the low germination of sample No. 3.

TABLE 8.—*Germination of dormant Grand Rapids lettuce from seed samples (series 6) held in tap water in darkness at 30° C. for 2 and 4 hours*

Sample No.	Time of soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Hours		*Percent*
1	2	Seed exposed to direct sunlight for 1 minute; dried in dark at 30°	11
2	2	Seed exposed to diffused light for 5 minutes; dried quickly in diffused light at 20°	22
3	2	Dried rapidly in diffused light at 32°	2
4	2	Seed held on damp muslin in diffused light in saturated atmosphere at 32° for 24 hours; dried in diffused light at 32°	1
5	4	Seed exposed to diffused light at 20° for 5 minutes; dried rapidly in darkness at 10°	20
6	4	Seed dried slowly on damp muslin in darkness at 10° after 5 minutes' exposure to light at 20°	98

[1] A percentage difference of 7.48 is required to show significance between treatments.

SERIES 7

The data presented in table 9 are from series 7, which consisted of 10 samples, including an untreated check. The treated samples were presoaked for 18 to 24 hours in darkness at 30° C. The results indicate that prolonged soaking at a temperature as high as 30° reduces the effectiveness of light, low temperature, and drying in stimulating germination following drying. Sample No. 3, which was exposed to diffused light for 3 hours at 20°, gave only 30-percent germination. Sample No. 6, which gave only 30-percent germination, indicates that low temperature is less effective following soaking for a long period at 30° than when the temperature during soaking is somewhat lower.

TABLE 9.—*Germination of dormant Grand Rapids lettuce-seed samples (series 7) held in tap water in darkness at 30° C. for 18 and 24 hours*

Sample No.	Time of soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Hours		*Percent*
1	18	Seed held on damp muslin in dark at 30° for 3½ hours; dried on damp muslin at 30°; not exposed to light.	2
2	18	Dried slowly in diffused light at 20°	15
3	18	Seed held on wet muslin in diffused light at 20° for 3 hours; dried quickly in diffused light at 20°.	30
4	18	Seed exposed to diffused light at 20° for 5 minutes; dried in darkness at 30°.	2
5	18	Dried quickly in darkness at 30°	2
6	24	Dried in darkness at 10°	30
7	24	Dried slowly in diffused light in moist atmosphere at 20°	24
8	24	Dried in darkness at 10°; never exposed to light	25
9	24	Dried in diffused light at 20°	12
10 (untreated check)			4

[1] A percentage difference of 9.30 is required to show significance between treatments.

SERIES 8

The samples in series 8 were given an initial treatment consisting of long periods of soaking in tap water in darkness at 30° C. Following the soaking, each lot was treated differently with regard to light exposure, temperature, and drying. The results of these tests, presented in table 10, indicate the inhibiting effect of long periods of soaking at high temperature and the ineffectiveness of light and low temperature following prolonged soaking at high temperature. In sample No. 2 the 72 hours in darkness at 10° followed by light exposure was ineffective in breaking dormancy. In sample No. 8, 24 hours' exposure to diffused light at 30° failed to break dormancy following the 6 days of soaking in tap water at 30°.

TABLE 10.—*Germination of dormant Grand Rapids lettuce seed (series 8) soaked in tap water in darkness from 2 to 6 days at 30° C.*

Sample No.	Time of soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Days		*Percent*
1	2	Seed held on wet paper in diffused light at 25° for 5 hours; dried in diffused light at 25°.	3.0
2	2	Seed held on wet paper in dark at 10° for 72 hours; dried in diffused light at 20°.	2.5
3	2	Seed exposed to diffused light at 20° for 10 minutes; dried slowly in the dark at 30°.	0
4	2	Dried in dark at 30° after 5 minutes' exposure to diffused light	3.5
5	4	Dried in diffused light at 20°	0
6	5	Dried in diffused light at 25°	0
7	5	Dried in darkness at 10°	6.0
8	6	Seed held on wet muslin in diffused light at 30° for 24 hours; dried in diffused light at 32°.	0
9 (untreated check)			5.0

[1] A percentage difference of 2.98 is required to show significance between treatments.

None of the treatments following soaking was effective in breaking dormancy after the long soaking at 30° C. In samples Nos. 3, 5, 6, and 8 the seed was all dormant as compared with 5-percent germination of the untreated checks.

That the seed in samples Nos. 3, 5, 6, and 8, in series 8, were not killed by the treatment was then proved. Treated seed from these samples, which had been in storage for 1 month, were soaked in water at 10° C. for 24 hours, then placed on wet paper in Petri dishes in diffused light for 48 hours at 20°. At the end of this period these lots gave the germination counts given in table 11. Results with sample No. 8, which gave 91-percent germination following the second treatment, indicate that the treatment at high temperature may have killed a small percentage of the seed.

The results from series 4, 5, and 6 indicate that soaking dormant lettuce seed in tap water at 30° C. reduces the effectiveness of the postsoaking treatments. Postsoaking treatments were less effective as the time of soaking at 30° was increased from 2 hours to 4 days. The holding of moist seed at a temperature of 30° has the same effect as soaking at the same temperature.

TABLE 11.—*Germination of lettuce seed given a favorable treatment following treatments at high temperature* [1]

[200 seeds in each sample]

Sample No.	Time of original soaking [1]	Germination after 48 hours in diffused light at 20° C., following 24 hours soaking in darkness at 10°					Seed germinated
		Lot 1	Lot 2	Lot 3	Lot 4	Total	
	Days	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
3	2	47	47	50	48	192	96.0
5	4	46	50	50	45	191	95.5
6	5	49	45	50	49	193	96.5
8	6	45	43	48	46	182	91.0

[1] See table 10.

Seed samples held in water at 40° C. for several days entered a dormant condition even more resistant to later exposure to light and low temperature.

SERIES 9

Flint (*3*) and Flint and McAlister (*4* and *5*) have presented data on the influence of light quality on the germination of lettuce seed. Flint found certain light rays in the red portion of the spectrum to be effective in stimulating germination of some lettuce seed. Flint and McAlister (*4*) report rays of 7,600 and 4,200 to 5,200 A. to have an inhibiting influence on the germination of some lots of lettuce seed. Flint and McAlister (*5*) present evidence to show that the critical wave length of light for promoting germination of lettuce seed is approximately 6,700 A.

Series 9 of the present studies was designed to determine the influence of light in the red portion of the spectrum as compared with diffused sunlight in stimulating germination in the dormant seed under study. This series consisted of seven samples, including an untreated check; six of the samples were treated in pairs, one member of each pair receiving red light and the other diffused sunlight. The results are presented in table 12.

TABLE 12.—*Germination of dormant Grand Rapids lettuce seed (series 9) receiving red and white light following soaking in tap water at 20° to 30° C.*

Sample No.	Time of soaking	Temperature during soaking	Treatment after soaking	Seed germinated after 72 hours in darkness at 25° C.[1]
	Hours	*° C.*		*Percent*
1	½	30	Held on wet muslin in diffused red light at 20° for 5 hours; dried slowly in red light at 20°.	98.0
2	½	20	Held on wet muslin in diffused sunlight at 20° for 5 hours; dried slowly in diffused sunlight at 20°.	97.5
3	2	27	Held on wet muslin in diffused sunlight at 27° for 3 hours; dried in diffused sunlight at 27°.	67.5
4	2	27	Held on wet muslin in red light at 27° for 3 hours; dried in red light at 27°.	83.0
5	3	30	Held on wet muslin in red light at 30° for 1½ hours; dried in diffused sunlight at 30°.	70.0
6	3	30	Held on wet muslin in diffused sunlight at 30° for 1½ hours; dried in diffused sunlight at 30°.	66.0
7 (untreated)				4.0

[1] A percentage difference of 11.13 is required to show significance between treatments.

Considering differences between red light and sunlight only, it will be seen that samples Nos. 1 and 2, which were soaked in tap water for a half hour at 20° C., gave practically the same response. Sample No. 4, which was exposed to red light, gave 83-percent germination, as compared with 67.5 percent for No. 3, which was exposed for 3 hours to diffused sunlight at 27°. Samples Nos. 5 and 6 showed no significant difference in germination due to the quality of light. The significant fact in this series of treatments is the decline in percentage of germination as the temperature and time of soaking was increased, although all of the treatments had a very beneficial influence on germination.

SERIES 10

Series 10 was designed to determine the effect of long periods of soaking at high temperature on the effectiveness of red light in stimulating germination. This series consisted of seven samples, including an untreated check. The treated samples, Nos. 1, 2, and 3, were soaked in tap water in darkness at 30° C. previous to the light treatment. Treated samples, Nos. 4, 5, and 6, were held on wet muslin in diffused red light for 5, 20, and 40 hours at 30°. The results are given in table 13.

TABLE 13.—*Germination data showing influence of red light on dormant Grand Rapids lettuce seed (series 10) treated at 30° C.*

Sample No.	Period in tap water or on wet muslin	Light relations during preliminary treatment	Treatment following soaking or exposure on wet muslin	Seed germinated after 72 hours in darkness at 25° C.[1]
				Percent
1	48 hours in tap water	Dark	Dried slowly in diffused red light at 20°.	6.0
2	do	do	Exposed to diffused sunlight at 30° for 10 minutes; held moist in dark at 30° for 48 hours; dried in diffused sunlight at 20°.	4.0
3	5 days in tap water	do	Dried slowly in diffused red light at 30°.	0
4	5 hours on wet muslin	Diffused red light	Dried in diffused sunlight at 30°.	77.5
5	20 hours on wet muslin	do	do	66.0
6	40 hours on wet muslin	do	do	2.0
7 (untreated check)				3.0

[1] A percentage difference of 8.76 is required to show significance between treatments.

The dishes in which germination tests were made in red light were covered with red cellophane No. 300. This product, according to the company's spectral analysis, filters out all light rays below 5,400 A. and transmits 2 percent at 5,400, 18 percent at 5,800, and 86 percent at 6,500 A.

Exposure to red light was ineffective in promoting germination in samples Nos. 1, 2, and 3. In samples Nos. 4, 5, and 6, which were exposed to red light, the percentage of germination declined with the increase in time of exposure. The results indicate that holding dormant lettuce seed for long periods in a moist condition at high temperature decreases the effectiveness of light in stimulating germination.

SERIES 11

Series 11 was designed to test the response of dormant lettuce seed to various treatments when the seed is germinated in soil. Treatments that had given poor, fair, and good results with seed germinated in Petri dishes in a germinator were used. The treatments were as follows: Seed was soaked in tap water (1) in diffused light at 32° C. for 2½ hours and dried slowly in diffused light at 32°; (2) for 3 hours in diffused light at 18° and dried in diffused light at 18°; (3) in diffused light at 7° for 2 hours and dried on damp muslin in darkness at 10°.

Four seed stocks known to exhibit some degree of dormancy were selected, and a portion of each was given the above treatments. After treating and drying, the seed was stored for 2 weeks before planting.

Four plantings, of 25 seeds each of both treated and untreated seed of each stock, were planted in soil in flats. The flats were placed on a greenhouse bench where the temperature varied from 20° C. at night to 30° during the warmest part of the day. Germination counts were made daily after the first seedlings appeared. Only the final counts made after 9 days are recorded. The germination of the untreated seed is given as the first four items in table 14; the germination of the treated lots of the four stocks are given in the lower portion of the table.

TABLE 14.—*Response of treated dormant lettuce seed (series 11) when germinated in soil*

Stock No.	Seed treatment	Seed germinated after 9 days in soil at 20° to 30° C.[1]
		Percent
1	Check	19
2		35
3		5
4		52
1	Soaked in tap water in diffused light at 32° C. for 2½ hours; dried slowly in diffused light at 32°	23
2		28
3		2
4		26
1	Soaked in tap water in diffused light at 18° C. for 3 hours; dried in diffused light at 18°	28
2		58
3		10
4		60
1	Soaked in tap water in diffused light at 7° C. for 2 hours; dried in the dark at 10°	34
2		97
3		36
4		70

[1] A difference of 7.10 percent is required to show significance between treatments.

The responses to the three treatments were much the same as those obtained when the seed was germinated in Petri dishes; however, in most tests in soil the percentage of emergence was less than the germination percentage in Petri dishes.

Treatment 1 gave very little or no increase in germination over the untreated seed; treatment 2 gave a very marked increase, although too low to be considered satisfactory; treatment 3 resulted in much higher germination than either treatment 1 or 2. However, stock

No. 3 gave only 36-percent germination under the most favorable treatment.

The important point in these tests is the increase in germination of the treated seed as the temperature during the treatment was decreased. Exposure to light was ineffective when the seed was treated and dried at high temperature.

A repetition of these tests in which the seed was planted in soil and covered with muck instead of soil averaged 25-percent higher germination than when soil was used as a covering for the seed.

Thompson (*10*) has presented the results of some investigations showing that soil texture and methods of watering may have a marked influence on the germination of lettuce seed. There is no doubt that many cases of failure of lettuce seed to germinate under field conditions may be traced to soil, moisture, and aeration, rather than to dormancy of the seed. Soil aeration is a very important factor in the germination of lettuce seed even though it shows no tendency to dormancy in laboratory tests.

GERMINATION OF DORMANT LETTUCE SEED AS AFFECTED BY CONSTANT AND FLUCTUATING TEMPERATURES

The data already presented indicate that temperature is one of the most important factors influencing the germination of dormant lettuce seed. In order to determine the influence of temperature alone on the germination of such seed, a number of tests were made in which the temperature was varied while other factors were kept as nearly constant as possible.

Five stocks of seed were selected for these tests. Stocks Nos. 1 and 2 were from lots of the variety Grand Rapids, and Nos. 3 and 4 were of the variety Hubbard Market. These four stocks were all known from previous tests to show some degree of dormancy. Stock No. 5 was from the variety Iceberg and was known to exhibit no tendency to dormancy.

The germination tests were made on damp muslin in 95-mm Petri dishes. One hundred seeds were used in each test. The percentage figures in table 15 are averages from 4 dishes of 25 seeds each. Each stock was germinated at constant temperatures of 10°, 22°, 25°, and 30° C. to determine the germination response of each at various constant temperatures.

After determining the germination response at constant temperatures, each stock was germinated under conditions in which the temperature was varied during the germinating period. In one series the germination was started at high temperature and later shifted to a lower temperature; in a second series it was started at a low temperature and later shifted to a higher one.

Light was excluded by placing the Petri dishes in covered boxes as soon as the seed had been placed on the wet muslin. The dishes were kept in the boxes until the counts were made in order to prevent light exposure during the shifting from one temperature to another.

The response of the five different stocks at constant temperatures is given in the first part of table 15. The nondormant stock, No. 5, germinated nearly 100 percent at all temperatures except 30° C.; stock No. 2 germinated 95 percent or better at 10° and 22°, but poorly above 22°; stocks Nos. 1, 3, and 4 germinated poorly at all constant temperatures; and No. 4 was very inconsistent in its response to

temperature, reaching its highest percentage of 24 after 72 hours at 25°.

TABLE 15.—*Germination of dormant and nondormant lettuce seed under various temperature conditions*

Temperature conditions during germination (°C.)	Seed germinated				
	Dormant stocks				Nondormant Iceberg, No. 5
	Grand Rapids		Hubbard Market		
	No. 1	No. 2	No. 3	No. 4	
GERMINATED AT CONSTANT TEMPERATURE					
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
72 hours at 10°	18	97	46	18	100
90 hours at 10°	19	95	48	17	100
72 hours at 22°	12	95	31	1	100
72 hours at 25°	3	63	0	24	98
96 hours at 30°	0	1	0	0	0
GERMINATION STARTED AT HIGH AND SHIFTED TO LOW TEMPERATURE					
6 hours at 30° 48 hours at 10°	10	90	25	0	100
20 hours at 30° 40 hours at 10°	0	2	0	15	90
20 hours at 30° 70 hours at 10°	8	35	1	95	100
24 hours at 30° 48 hours at 10°	0	3	0	3	100
24 hours at 30° 24 hours at 5°	0	2	0	0	100
48 hours at 30° 48 hours at 30° 24 hours at 10°	7	11	1	32	100
48 hours at 25°					
GERMINATION STARTED AT LOW AND SHIFTED TO HIGH TEMPERATURE					
6 hours at 10° 48 hours at 25°	46	100	87	94	100
24 hours at 10° 20 hours at 30°	5	65	6	6	100
20 hours at 10° 24 hours at 30° 48 hours at 10°	37	98	80	80	99
48 hours at 10° 24 hours at 30° 48 hours at 10°	8	94	18	50	100
48 hours at 32° 48 hours at 10°	6	83	31	42	100
48 hours at 22° 72 hours at 5°	45	100	100	98	100
24 hours at 22°	96	100	95	65	100

The second part of table 15 gives the response of the five stocks when germination was started at 30° C. and later moved to a lower temperature. The nondormant stock, No. 5, germinated well under all conditions. The four dormant stocks germinated very poorly in nearly every case when the germination was started at 30°. Stock No. 4 was inconsistent in its response, as it was at the constant temperatures. This stock gave the high percentage of 95 when held for 20 hours at 30° and then held for 70 hours at 10°. Stock No. 2 germinated 90 percent when held at 30° for 6 hours and then at 10°

for 48 hours. Low temperature following a period of high temperature failed in most cases to induce the dormant seed to germinate.

The influence of low followed by high temperature is shown by the germination data presented in the last part of table 15. Low temperature followed by a higher temperature resulted in much higher germination percentages than either constant temperature or a shift from high to low temperature, indicating the beneficial influence of such change. The germination counts from tests where the temperature was increased from 5° or 10° C. to 22° or 30° averaged much higher for all of the dormant stocks than at constant temperatures except stock No. 2, which germinated 95 percent or better at constant temperatures of 10° and 22°.

It will be noted that all of the four dormant stocks germinated nearly 100 percent under some of the temperature conditions used, showing that satisfactory germination could be obtained with temperature control without exposure to light.

It was possible by temperature control alone to obtain nearly 100-percent germination of the four stocks of dormant lettuce seed studied.

DISCUSSION

The data recorded in the course of these tests show that seeds of some varieties of lettuce may remain in a condition of dormancy which prevents their germination in darkness at 25° C. for a long period after harvest. It seems likely that in some cases this dormant condition may continue so long that some of the seed loses its viability due to age without coming out of dormancy under storage conditions. In many cases, however, a short period in storage may be sufficient to break the dormancy.

Evidence is presented in tables 5, 6, and 7 indicating that soaking seed in water for a few hours, exposing it to diffused light at temperatures at or below 25° C., and then drying it slowly at low temperature with good aeration is effective in inducing a high percentage of germination in dormant lettuce seed. Seed so treated may be kept in storage for several weeks before planting, yet give good germination in darkness at 25°. These results indicate that soaking in water at low temperatures (5° and 10°) for as long as a week does not reduce the effectiveness of the postsoaking treatment.

The results obtained from tests presented in tables 8, 9, and 10 indicate that temperatures above 25° C. during any stage of the treatment results in much poorer germination than when treatments are carried out at lower temperatures. The longer the moist seed was exposed to high temperatures, the less effective was the treatment in promoting germination. Prolonged soaking in water at 30° greatly reduced the effectiveness of the postsoaking treatments.

Exposure of moist seed to diffused light for even a short period has a very favorable influence on germination, providing the treatment is carried out at relatively low temperatures. The effectiveness of light decreased as the temperature during treating and the time of exposure to high temperatures increased. The relationship between temperature and light is such that no particular temperature can be said to be critical for the effectiveness of light in its influence on germination. However, the results indicate that light loses its

influence rapidly as the temperature increases above 25° C. and that its influence becomes more marked as the temperature declines below 25°.

The germination of seed samples Nos. 1 to 8, presented in table 10, are typical of the results obtained with seed that had been soaked in water for long periods in darkness at 30° C. Even long exposure to diffused sunlight was ineffective when the seed had been soaked for long periods in darkness at high temperature or when it was high during exposure to light and drying. Long soaking at high temperature or the holding of moist seed at high temperature with poor aeration brings about a condition difficult to correct unless the seed is thoroughly dried and re-treated. Low temperature and light exposure are less effective after seed has been held in a moist condition at high temperature than is the case when the seed is never exposed to high temperature after becoming moist.

If seeds that have been forced into an extreme condition of dormancy by holding at high temperature while moist are thoroughly dried, they respond to light and low temperature and give about the same percentage of germination as the original untreated seed. This is shown by the results given in table 11. A portion of the seed from samples Nos. 3, 5, 6, and 8, which were shown to germinate poorly following the treatment at high temperature (table 10), was given a favorable treatment at low temperature with light exposure. The percentage of germination following the subsequent treatment was fairly high, indicating that the high-temperature treatment had not killed the seed, but had held it in a dormant condition.

The data presented in tables 12 and 13 indicate that light, whether the full spectrum or the red portion, loses its effectiveness with increase in temperature during the treatment.

Germination tests of treated and untreated lettuce seed from stocks known to exhibit some degree of dormancy made in soil gave much the same results as were obtained from the same stock when germinated in Petri dishes in a seed germinator, except that in most cases the emergence percentage was lower in soil (table 14). The low-temperature treatment with light exposure gave much higher germination than treatment at high temperature with light exposure. Lettuce seed, whether nondormant or dormant, in which dormancy has been broken by treatment, requires good aeration during germination. If aeration is poor, germination may be low, even though the seed is capable of germinating at the temperature employed. Lettuce seed planted in soil and covered with muck or sand always germinates more rapidly and gives a higher germination than the same seed covered with fine soil. This is especially true if the surface soil is wet following planting. Many cases of poor germination of lettuce seed under field conditions can doubtless be traced to poor soil aeration rather than to seed dormancy.

The results obtained in these studies indicate that it is possible greatly to increase the germination of dormant lettuce seed by treatments that permit it to be dried and stored for some time thereafter, making it possible to plant the seed with a mechanical seeder without danger of injury.

It is obvious that the factors influencing the germination of dormant lettuce seed form a complex interrelationship and that no particular combination of these factors can be said to be the most favorable for the germination of all lots of dormant seed. Treatments resulting in

100-percent germination of some seed will not be entirely effective with other more dormant lots, because temperature, light, aeration, moisture, and the germinating medium all influence the process. Doubtless temperature is generally the most important single factor, and its control is essential in any treatment designed to break dormancy where the seed is to be dried thoroughly before planting. Light exposure has a very stimulating influence, provided the treatment is made at a relatively low temperature.

The duration of the various phases of the treatment is very important. The temperature during that phase of the treatment in which the seeds are allowed to imbibe water may be fairly high, provided the time of soaking is short; 2 or 3 hours is probably sufficient time to hold seed in water. The most important factors in the treatment are the temperature and the time that the moist seed is held between soaking and drying. During this period the temperature must be low; that is between 10° and 20° C. The studies made indicate that very low temperatures which prevent germination (5° or below) are probably not as effective as those between 10° and 20°, and more time is required to complete the treating than if the temperature is favorable for germination.

Best results were obtained where the entire treatment including soaking was done at low temperature. A sharp change in temper a ture from low to high during the treatment process appears to haveabeneficial influence not obtained when it is carried out at a constant temperature, although the temperature be low.

The results obtained indicate that consistently high germination can be expected from dormant lettuce seed that is soaked for 2 or 3 hours in water in darkness at 5° to 10° C., and is then spread thinly on a moist surface, such as damp muslin, and exposed to diffused sunlight for 15 to 30 minutes followed by slow drying on a moist surface at about 10°. Satisfactory results can be obtained with considerable variation from this procedure, but this is a good practice to follow as near as possible. Soaking at 10° is perhaps about as effective as soaking at 5°, except that there appears to be a beneficial effect resulting from the change in temperature during the treatment. Only a few minutes' exposure to light may be required in the case of slightly dormant seed.

Control of conditions during the drying phase of the treatment is very important. Best results were obtained when the drying was done in darkness following exposure to diffused light after the soaking. The drying should be slow, in order that the seed be held in a favorable condition a sufficient time for the germination processes to start. However, this period should not be too long, as the germination process may advance so far that the drying later may result in the death of the more advanced embryos.

It is very important that drying be done under conditions of good aeration. Very satisfactory drying may be obtained by spreading the moist seed on a piece of damp muslin following its exposure to light and placing the muslin on a wire tray in an ice box at about 10° C., leaving the seed and muslin to dry out slowly. The muslin should be only damp enough to hold the seed in a moist condition for 5 or 6 hours, otherwise some of them may germinate before the muslin dries out sufficiently to stop the germination process at the right

stage. Good results were obtained by folding the wet muslin after the seed had been spread on it and wringing it by twisting until the cloth was only moist. This leaves only enough moisture to keep the seed damp for a few hours. The seed should not be folded in the muslin but left exposed to the air. A screen tray which will permit free circulation of air is preferable to a solid tray for holding the cloth during the drying. When the cloth and seed are thoroughly dry the seed may be placed in a container and kept at room temperature for 2 or 3 weeks and perhaps longer before planting without appreciable change in germination. The artificial control of temperature during seed treatment may not be important during cool weather, but if seed is to be treated during warm summer weather when air temperatures are high, equipment for the careful control of temperature is essential.

CONCLUSIONS

Natural dormancy in lettuce seed may vary in degree between very slight, easily broken dormancy and an extreme dormant condition, very difficult to correct by treatments.

A condition of dormancy not naturally present in lettuce seed may be induced by exposure of moist seed to high temperature (30° C. or above).

Light has a very marked stimulating influence on dormant lettuce seed when moist seed is exposed to it at temperatures below 20° C.

The influence of light in stimulating germination of dormant lettuce seed decreases as the temperature at which the moist seed is exposed is increased above 20° C.

Good aeration during treatment to break dormancy is essential if the seed is to be dried before planting or making germination tests.

Dormancy induced or intensified by exposure of moist seed to high temperature is difficult to correct unless the seed is dried and given a subsequent favorable treatment at low temperature.

Poor soil aeration, resulting from surface irrigation following planting or from other causes, may result in poor germination of any lettuce seed, whether naturally dormant or not.

Very high soil moisture during periods of high temperature may result in poorer germination than would be obtained if the soil-moisture content were just high enough to provide sufficient moisture for germination.

The factors influencing the germination of dormant lettuce seed form a complex interrelationship, and no single element of the environment, whether light, temperature, aeration, moisture, or something else, appears to be the one critical element. Nor can any particular combination of these factors be said to afford the most favorable environment for the germination of all lots of dormant lettuce seed.

The germination of nearly all lots of dormant lettuce seed can be increased by treatments that will permit the seed to be dried and stored for some time after treating. It can be greatly increased by soaking the seed in water for a few hours at 5° to 15° C., then exposing the moist seed to diffused light for a few hours under conditions of good aeration at a temperature below 20°, followed by slow drying at low temperature. Seed thus treated may be stored for some time after treating and still germinate much better than the untreated seed.

Fluctuating temperatures starting low and shifting higher are more effective in the germination of dormant lettuce seed than constant temperature, whether high or low.

A fairly high percentage of germination of many lots of dormant lettuce seed can be obtained by control of temperature alone without light exposure, provided the germination process starts at a low temperature, 5° to 10° C., followed by a later shift to a higher temperature, 22° to 30°.

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