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Freezing Injury of Seed Corn

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T. A. Kiesselbach and J. A. Ratcliff

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CONTENTS

SUMMARY

1. Injury to seed corn by freezing in the fall is of frequent occurrence in Nebraska. The underlying causes of such injury are: (1) Late maturity, (2) abnormally early freezing weather.

2. The embryo, which is the vital part of a corn kernel, is in reality a rudimentary corn plant, having small leaves, stalk, and root.

3. In the normal process of germination, or growth of the embryo, the primary root develops more rapidly than the plumule.

4. The embryo and endosperm of a kernel of corn develop approximately at the same rate from the time of fertilization until maturity, and the power of germination is attained in about 20 days after fertilization.

5. The embryo and endosperm in an air-dry kernel of corn contain practically the same percentage of moisture. However, during the period just before maturity the percentage is greater for the embryo.

6. When immature or moist kernels of corn are sufficiently exposed to freezing temperatures, ice is formed in the intercellular spaces and in the larger spaces around the scutellum, plumule, primary root, and root sheath.

7. Severe freezing of immature or moist corn causes the embryo to change from a normally light or creamy color to a dark or yellowish brown color. This change is usually accompanied by a loss of vitality. The appearance of the embryo, therefore, is a fairly safe guide in judging the germinative power of seed corn which has been subject to freezing injury.

8. So far as could be detected from microscopic examinations of frozen embryonic tissues, there was no rupturing of cell walls or other cytological effect of freezing and ice formation. The change in color of the embryo as a result of freezing would seem to indicate that a chemical change had taken place.

9. The real cause of death from freezing of plant tissues is a difficult matter to determine. Nevertheless, several theories based on certain observations have been advanced to explain it. The most generally accepted theory is that water is withdrawn from the cells during the process of freezing, and that this process continues until death results from desiccation of the protoplasm. The most satisfactory explanation, however, in the light of the evidence at hand, is found in the theory, that freezing produces a physical or chemical change, aside from the withdrawing of water, in the protoplasmic and nuclear material of the cell so that the element of life no longer exists.

10. Death from freezing is directly related to the moisture content of the kernel and also to the duration of the exposure to cold. Seed corn maturing in a natural way becomes cold resistant progressively as its moisture content diminishes. Seed corn mortality increases progressively as the duration of the killing temperature is extended. Seed corn samples containing various amounts of moisture were husked from the field and subjected artificially for twenty-four hours to various freezing temperature ranges. After freezing, parts of each sample together with corresponding unfrozen samples were allowed to thoroly cure, after which germination tests were made. The relative germination of the frozen and the unfrozen samples indicates the degree of freezing injury upon the viability as follows:

Temperature Ranges	Moisture Content of Grain (Per Cent)										
	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65
Degrees F.			*Relative germination (Per cent)*								
32 to 28..	...	...	100	85	75	71	69	...	33	31	0
24 to 20..	...	100	96	77	67	13	12	12	6	0	0
16 to 12..	...	100	88	34	12	0	0	0	0	0	0
8 to 4..	100	98	47	7	0	0	0	...	0	...	...
0 to -5..	97	63	0	0	0	0	0	0	0	0	0

Where data are lacking no tests were made.

11. The vitality of corn containing from 15 to 20 per cent of moisture will not be injured by ordinary autumn freezing; and corn with 10 to 14 per cent of moisture will stand the most severe winter temperatures without injury to its germinative power.

12. The kernels upon an ear of corn may vary in moisture content which may explain partial germination of an ear of corn after exposure to freezing temperatures.

13. Ice formation within the kernel is not necessarily fatal to the vitality of the germ.

14. The variation in time of freezing weather together with the great seasonal variation in time of corn maturity makes freezing injury inevitable in occasional years.

15. The best adapted types of corn for Nebraska conditions should ripen two or three weeks before the mean date of the first killing frost for the locality in which they are grown.

16. Varieties which ripen too late may be made to ripen earlier (1) by field selection of seed from the earlier maturing

plants before autumn frosts, and (2) by selection of the drier and more mature ears later in the season. Such late varieties may often be advantageously replaced by securing seed of some earlier variety.

17. The conditions are very exceptional in which a satisfactory seed supply cannot be obtained by any of the three following methods: (1) Special early field selection before any likelihood of frost. (2) Selecting seed late in September, or early in October while husking corn in the regular way for early feed. (3) Selecting seed while picking corn to crib in the forepart of the husking season. The relative merits of these three methods will vary according to conditions.

Crib selection of seed corn may be practiced as a last resort if provision for a seed supply by other methods has been overlooked. In years when corn matures well it is a very good and safe practice to select sufficient seed for two years' planting.

18. The viability of seed corn should be ascertained before planting time. This may be done in a general way by a general germination test or by observing the color of the germ. Dark or discolored germs possess little or no vitality. If either of these methods indicate a rather low vitality, a more severe elimination of unsound seed should be made by the individual ear germination test.

19. By a comparison of the yields of corn following years of serious seed corn injury with the average yield of corn for Nebraska during the last 28 years, it seems that predictions of low yields following years of severe seed injury are not justified.

20. Corn harvested early in the fall and given special care in preservation will not outyield seed which has been exposed in the field to the cold winter without special care, provided both are selected for high germinative qualities. As an average for three years, 1915 to 1917, seed corn harvested by special selection from the field in September, November, and March, and given good care after selection, yielded respectively 48.2, 49.6, and 51.2 bushels per acre, while seed saved from the same field during the regular process of husking in November yielded 50.6 bushels per acre.

21. In a comparison of ear types of Nebraska White Prize corn during the four years 1914 to 1917, a long, slender, smooth type of ear yielded 58.8 bushels per acre, which is 0.7 bushels more than the original corn, 7.4 bushels more than the large rough ears, 1.7 bushels more than the short rough ears, and 2.1 bushels more than the short smooth ears. One may conclude that this long, slender, smooth type possesses highly satisfactory

yielding qualities, which, coupled with its superior germinative ability, makes it a very suitable type to grow.

22. Uniform and varied distribution of seed corn in the field were compared for yield of grain. It was found that there may be much irregularity in stand without a material effect upon yield. As an average for the years 1915 and 1916, a uniform stand of three plants per hill yielded 1.8 per cent more than the mean for the varied distributions in which successive hills contained (a) 1, 2, 3, 4, and 5 plants, (b) 2 and 4 plants, and (c) 1, 3, and 5 plants. This is greater irregularity than results from mechanical variation of corn planters, or from planting 75 per cent germinating seed corn at the rate of four plants per hill.

23. Comparative yields were obtained during two years for corn hills containing one, two, or three plants, when surrounded by hills with three plants. Two-plant hills and one-plant hills yielded respectively 18 per cent and 39 per cent less than a three-plant hill. Fifty per cent of the yield lost in a hill with one missing plant was recovered in the four nearest adjacent hills at right angles. Seventy-two per cent of what was lost in a hill with two missing plants was recovered in the four nearest adjacent hills. Fifty-six per cent of what was lost in a hill with no plants was recovered in the four nearest adjacent hills. It is probable that this recovery also extends at least to the four nearest diagonal hills.

24. An application of the law of chance to the random distribution of sound kernels shows: (1) When 75 per cent germinating seed is planted four per hill, 31.6, 42.3, 21.1, 4.6, and 0.4 per cent of the hills will contain 4, 3, 2, 1, and no sound kernels respectively. These percentages were borne out by actual test. (2) If corn testing 65 per cent germination is planted at the rate of 4 kernels per hill, 17.8, 38.5, 31.1, 11.1, and 1.5 per cent of the hills will contain 4, 3, 2, 1, and no sound kernels respectively. (3) If corn is planted only half of which will grow, at the rate of 5 per hill, 3.1, 15.6, 31.3, 31.3, 15.6, and 3.1 per cent of the hills will contain 5, 4, 3, 2, 1, and no plants.

The actual distribution from a planter will vary somewhat from the above figures for the reason that no mechanical planter will uniformly drop a given number of kernels. The use of low germinating seed corn requires a definite knowledge of the germination percentage which can only be accurately determined by a properly conducted germination test.

FREEZING INJURY OF SEED CORN

T. A. KIESSELBACH AND J. A. RATCLIFF

INTRODUCTION

Injury to corn for seed purposes by freezing in the fall is of frequent occurrence in Nebraska and thruout much of the corn producing area of the world. The underlying causes of such injury may be (1) late maturity and (2) abnormally early freezing weather. Late maturity may result from (1) late planting, (2) planting of unadapted varieties, and (3) peculiar weather conditions which do not favor early ripening. Undue early freezing may work similar injury to corn that would possess strong vitality under normal weather conditions. When subjected to a severe frost, immature corn suffers a partial or total loss of germinative power.

The object of the investigations in this bulletin has been to determine the conditions under which freezing injury may occur to seed corn; to indicate, if possible, the vital changes in the embryo resulting in such injury; and to point out ways by which seed corn of strong vitality and satisfactory yielding capacity may be obtained.

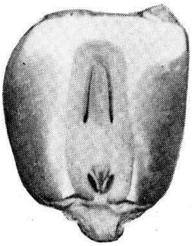
CHARACTER OF THE CORN EMBRYO AND PROCESS OF GERMINATION

The relation of the embryo to the remainder of the kernel of dent corn may be seen in Figures 1 and 2, which are vertical and cross sections respectively. The starchy and horny endosperm may be distinguished surrounding the embryo, which consists of the plumule, primary root, and scutellum. When placed under heat and moisture conditions proper for germination, enzymes are secreted by the scutellum of a viable corn kernel, which convert the food materials stored in the endosperm into forms which may be used for nourishing the young plant.

In Figure 3 the pericarp or seed coat of a germinating kernel has been removed to show the development which took place during 35 hours of favorable germination conditions. The root develops more rapidly than the stem.

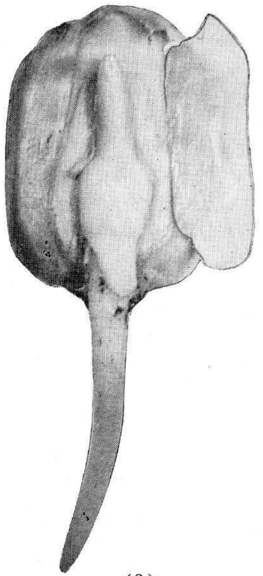
The effect of 20 hours additional germination is shown in Figure 4. Three secondary roots have started growth from the base of the plumule.

The differentiation of tissues and organs in the embryo of a mature kernel of corn is shown in Figures [1]5-8. Figure 5 is a cross section thru the plumule surrounded by the scutellum. It may be seen how the young leaves are closely folded or curled up within the plumule. Figures 6, 7, and 8 are vertical sections



(1)

(2)



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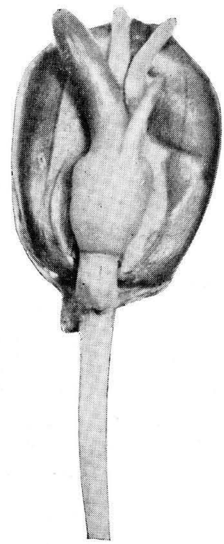

(4)

Fig. 1—Vertical section of kernel of dent corn.
Fig. 2—Cross section of kernel of dent corn.
Fig. 3—Growth after 35 hours favorable germination.
Fig. 4—Growth after 55 hours germination showing secondary roots.

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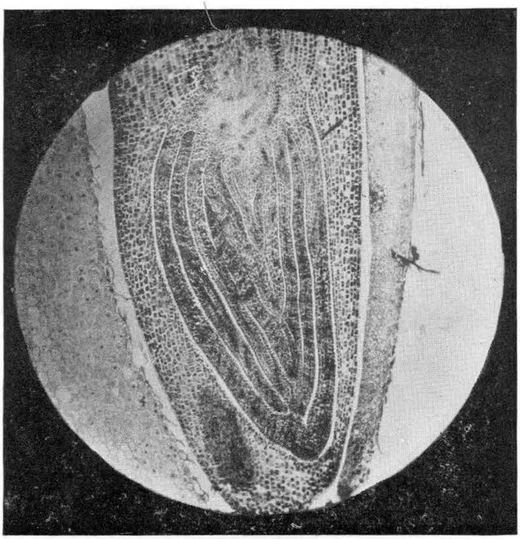
1. The material from which these photographs were taken was secured from a yellow variety of ordinary dent corn, Hogue's Yellow Dent. After soaking several kernels in water for about 12 hours, the scutellums were removed and dropped at once into Bowan's Picric formol killing and fixing solution. They remained in this solution for 10 hours. Washing with 70 per cent alcohol was then begun and continued until the material appeared whitish and the alcohol was no longer tinted yellow. The material was then dehydrated in 85, 95, and 100 per cent alcohol, after which it was cleared by bringing it up thru the xylol series. This consists of an alcoholic dilution of xylol in the following proportions: (1) 1 part xylol, 3 parts alcohol; (2) 2 parts xylol, 2 parts alcohol; (3) 3 parts xylol, 1 part alcohol; (4) pure xylol. Infiltration with paraffin was then begun by placing the material, together with a small block of paraffin, in a bottle of pure xylol. It remained in this bottle overnight and was then removed to the paraffin bath, where it remained for about 10 hours, and was then imbedded in paraffin. Sections were made of this material in the usual way and fastened on slides. The paraffin was removed from the sections with xylol, and the xylol removed with 95 per cent alcohol. This prepared them for the stain, methylene blue being used. They were stained for about 2 minutes and then dehydrated in 95 and 100 per cent alcohol, cleared with xylol, and mounted in balsam. The material was then in permanent form and could be studied under the microscope at any time.



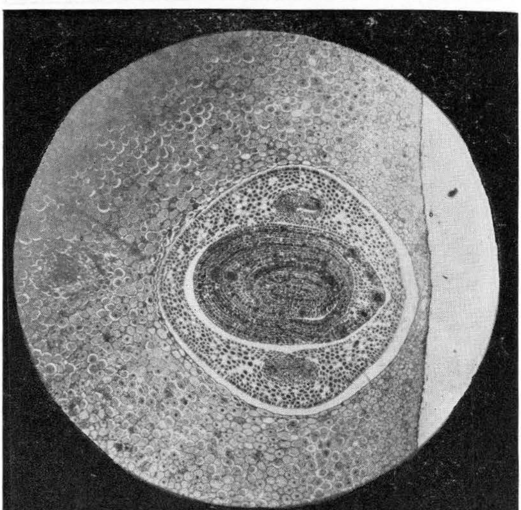
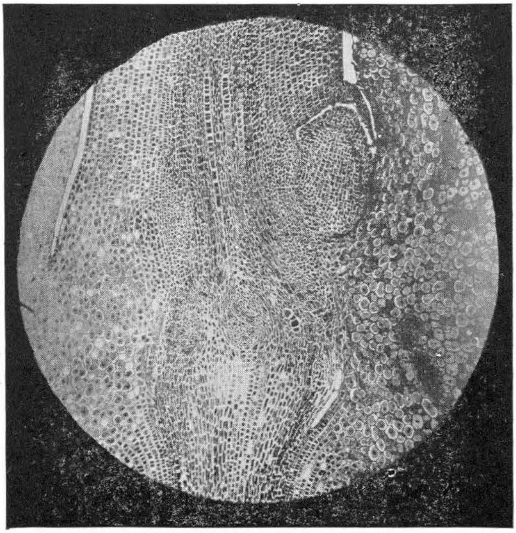


Fig. 5 (upper)—Micro-photograph of cross-section thru plumule of corn embryo

Fig. 6 (lower)—Vertical section thru plumule of corn embryo, showing leaf formation



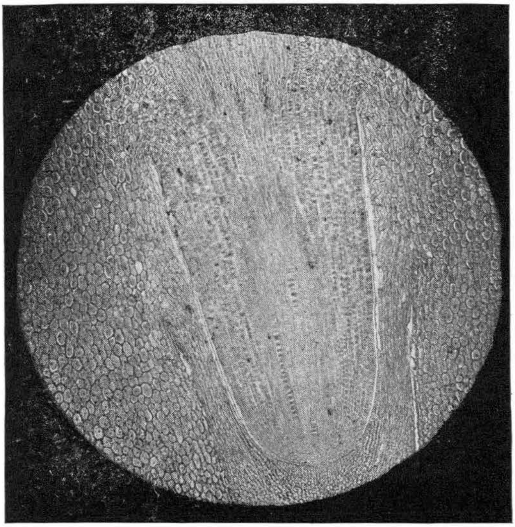


Fig. 7 (upper)—Micro-photograph of vertical section thru the medial area between the plumule and root of a corn embryo. Origin of plumule, primary root and secondary root are visible

Fig. 8 (lower)—Vertical section thru the primary root of a corn embryo respectively thru (1) the plumule, (2) the medial area between the plumule and root, and (3) the primary root. The embryo is seen to be a miniature plant, with its vegetative organs fairly distinct.

FREEZING INJURY NOT DUE TO ARRESTED DEVELOPMENT OF THE EMBRYO

The loss of vitality or lack of germinative power occasioned by autumn freezing is not due merely to arrested development of the seed. There is much experimental evidence as well as general observation that corn acquires the power of germination very early in the development of the kernels. Corn

TABLE 1—*Viability of corn harvested at various stages of maturity (1915-1917)*

Date of selection[1]			Weight of 100 kernels			Germination		
1915	1916	1917	1915	1916	1917	1915	1916	1917
			Grams	*Grams*	*Grams*	*Per cent*	*Per cent*	*Per cent*
Aug. 22	Aug. 22	Aug. 28	11.2	15.4	10.0	66	83	92
Aug. 29	Aug. 29	Sept. 4	16.0	19.7	15.4	88	94	94
Sept. 5	Sept. 5	Sept. 11	18.9	22.3	20.0	89	94	99
Sept. 12	Sept. 12	Sept. 18	23.0	25.9	23.8	95	96	99
Sept. 19	Sept. 19	Sept. 25	27.0	28.2	28.6	96	96	99
Sept. 26	Sept. 26	Oct. 2	29.9	31.4	30.9	94	96	99
Oct. 3	Oct. 3	Oct. 9	31.0	32.3	31.0	96	97	100

[1]Corn was in the milk stage at the first selection each year.

Date of selection	Condition of grain	Three year average			
		Days since fertilization[3]	Weight of 100 kernels	Ratio wt. of embryo to wt. of kernel[2]	Germination
			(*Grams*)		(*Per cent*)
Aug. 24	Milk stage	20	12.2	.078	80
Aug. 31	Late milk stage	27	17.0	.105	92
Sept. 7	Roasting ear	34	20.4	.110	94
Sept. 14	Late roasting ear	41	24.2	.103	97
Sept. 21	Denting	48	27.9	.106	97
Sept. 28	Glazing	55	30.7	.112	96
Oct. 5	Mature	62	31.4	....	98

[2]Data for 1917 only.

[3]Pollination occurred on August 1, July 31, and August 10, in 1915, 1916, and 1917 respectively.

harvested in the "milk" stage has been found to give a fair percentage of germination, and a perfect germination may be secured from seed harvested in the early "dough" stage.

In the seasons of 1915, 1916, and 1917, seed of Hogue's Yellow Dent corn was selected at successive stages of maturity. Immediately after being selected the seed was hung in a dry, airy place and thus cured free from mould or other injury. It was tested for germination late in the winter after becoming air-dry. The results are shown in Table 1.

The average date of pollination during the three years was August 3. This would indicate that the date of fertilization of the ovules was August 4. The average date during the three years of the first selection of corn was August 24, which is approximately twenty days later than the date of fertilization. This first selected seed which had but three weeks development after fertilization weighed only 39 per cent as much, moisture-free, as the best matured seed. Nevertheless, in spite of this premature selection, the earliest gathered seed germinated 80 per cent on an average. The moisture-free weights of 100 kernels for the successive selections were respectively 12.2, 17.0, 20.4, 24.2, 27.9, 30.7 and 31.4 grams. The respective germinations of these seven lots of seed were 80, 92, 94, 97, 96 and 98 per cent.

The germinative ability of very immature corn does not appear to be, as is commonly believed, due to more rapid growth and earlier maturity of the embryo than takes place in the endosperm. The embryo does not mature early with a later filling in of the endosperm. But rather both develop in approximately the same ratio as will appear in Table 2.

TABLE 2—*Relative development of embryo and kernel of Hogue's Yellow Dent corn harvested at various stages of maturity (1917)*

Sample number	Condition of grain	Date of harvest	Days since fertilization of kernel	Moisture-free weights of			
				100 kernels	100 embryos	100 kernels without embryo	Ratio of embryo to kernel
				Grams	*Grams*	*Grams*	
1	Milk stage	Aug. 28	18	8.28	0.65	7.63	.0785
2	Late milk stage	Sept. 4	25	13.45	1.41	12.04	.1048
3	Roasting ear	Sept. 11	32	17.54	1.94	15.60	.1106
4	Late roasting ear	Sept. 18	39	21.17	2.18	18.99	.1030
5	Denting	Sept. 25	46	25.10	2.67	22.43	.1064
6	Glazing	Oct. 2	53	28.04	3.12	24.82	.1117

For this test, grain harvested at the first six different stages of maturity in 1917 and described in Table 2 was used. The grain was soaked for a short time in water in order to facilitate an accurate separation of the embryo from the rest of the kernel. The relative moisture-free weights of 100 representative kernels and their embryos were determined for each stage of maturity. The moisture-free weights of 100 seeds for each stage were respectively 8.28, 13.45, 17.54, 21.17, 25.10, and 28.04 grams, while the moisture-free weights of the embryos were respectively 0.65, 1.41, 1.94, 2.18, 2.67, and 3.12 grams. The respective ratios of weight of embryos to total weight of

Fig. 9—Representative kernels of Hogue's Yellow Dent corn harvested at various stages of maturity in 1917. Top row shows the condition 20 days after fertilization of ovule; second row from top, 27 days; third row from top, 34 days; fourth row from top, 41 days; fifth row from top, 48 days; bottom row, 55 days. See Table 2

kernel were .078, .105, .110, .103, .106, and .112. With the exception of the least mature grain, the embryo bore practically a constant relation to the whole kernel regardless of the stage of maturity. For the earliest selection the proportion of embryo was the lowest. This may be accounted for in part by the fact that the initial development of the kernel, prior to fertilization, is a greater factor in the relative weights of the embryo and kernel than at any succeeding time.

When corn was harvested 27 days after fertilization, the scutellum measured 7 millimeters long and the germ from tip of plumule to tip of root was 5 millimeters long. For corn harvested 55 days after fertilization, the length of the scutellum was 9 millimeters, while the germ from tip of plumule to tip of root was 7 millimeters.

MOISTURE CONTENT OF CORN

Since the moisture content of corn is a factor in freezing injury, data were secured to determine the relative moisture content of the embryo and the endosperm. It was thought that this might help to throw some light on the effect of freezing and might perhaps indicate where freezing does its greatest damage. Tests were made with both old and new corn, the results of which are given in Table 3.

Old Corn. The tests with the old corn were of a preliminary nature. In order to insure differences in moisture content, the corn was divided into three lots and treated as follows:

(1) Lot 1 consisted of air-dry corn.

(2) Lot 2 had been placed in a bed of cool, damp soil and allowed to remain for 24 hours.

(3) Lot 3 had been buried in cool, damp soil for 48 hours.

The embryos were then separated from the endosperms of all samples, and moisture determinations made.

The results indicate that in the air-dry condition, the moisture content of the embryo is likely to be as low or lower than in the endosperm. The ratio of the moisture content of the embryo to that of the endosperm was 1.03. In the lot of seed buried in cool, damp soil for 24 hours, the embryos had taken up more moisture than had the endosperms. Here the ratio of the moisture content was 1.36. This difference increased in a still greater degree in the lot buried for 48 hours, the ratio here being 1.77. This represents somewhat the condition of the kernels in the fall before having thoroly cured.

TABLE 3—*Relative moisture content of embryo and endosperm*

Description of grain	Moisture content		
	Embryo	Endosperm	Ratio embryo to endosperm
OLD CORN	*Per cent*	*Per cent*	
Air-dry	7.91	7.6	1.03
Embedded 24 hours in moist soil	21.37	15.62	1.36
Embedded 48 hours in moist soil	36.81	20.83	1.77
NEW CORN			
Selected from field before dry	31.1	24.1	1.29
Same corn when practically air-dry	10.5	12.9	0.81

New Corn. Twenty-five seed ears were selected in the fall before becoming well dried out. Twenty kernels were removed from each ear and the relative moisture content of the embryo and endosperm determined, giving a ratio of 1.29. When this corn had become practically air-dry, the ratio of the moisture content of the embryo to that of the endosperm was reduced to 0.81.

PHYSICAL EFFECTS OF FREEZING

ICE FORMATION IN KERNELS

It is known that ice is formed in kernels of immature corn when exposed sufficiently to freezing temperatures, and that death frequently follows such exposure. The temperature at which ice is formed within the corn kernel depends very largely upon the moisture content of the kernel. For the most immature seed tested in these experiments, containing 60 to 80 per cent moisture, the freezing point was only slightly below the freezing point of water. On the other hand, no ice formation could be detected in air-dry kernels or in kernels containing less than 18 per cent of moisture, when subjected to the lowest temperature observed; namely 10° F. below zero.

During the freezing process, in case the moisture content was excessive, the water seemed to be drawn from the cells into the larger spaces around the embryo, and about the plumule, the primary root, and the root sheath, and doubtless into the smaller spaces between the cells. In these larger spaces, which may be seen in Figures 1, 2, 5, 6, 7, and 8, the ice would form in a solid sheet around the tissues. In fact, when very moist kernels were exposed to the lower temperatures, the whole kernel appeared to be a solid frozen mass. The open spaces in and around the embryo also appeared to be enlarged by the ice formation.

Usually where ice was formed in the kernels, and remained in a frozen condition for practically 24 hours, the vitality was destroyed or weakened. In a few cases, however, ice was noted and still the vitality of the kernel remained unimpaired. Ice formation within the kernel, therefore, even when a coat is formed around or partly around the embryo, does not necessarily mean death. The retention of life depends quite largely upon the duration of the frozen condition. Data regarding the relation between ice formation and injury are given in Tables 5 to 12. In cases where the freezing was severe, frozen kernels were left in a soft, watery condition after thawing. The cells seemed to be unable to absorb the water which had been drawn from them during the freezing process.

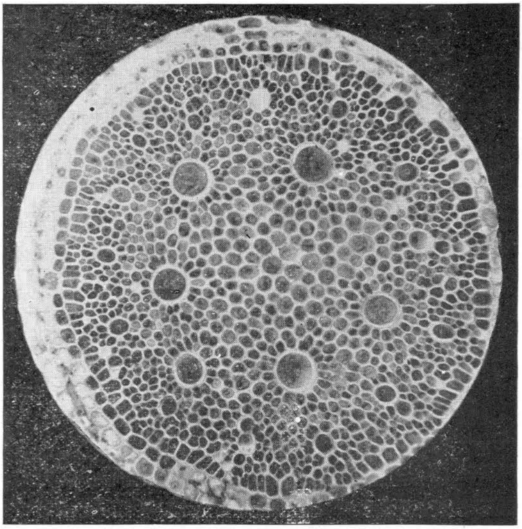
EFFECT OF FREEZING ON COLOR OF EMBRYO

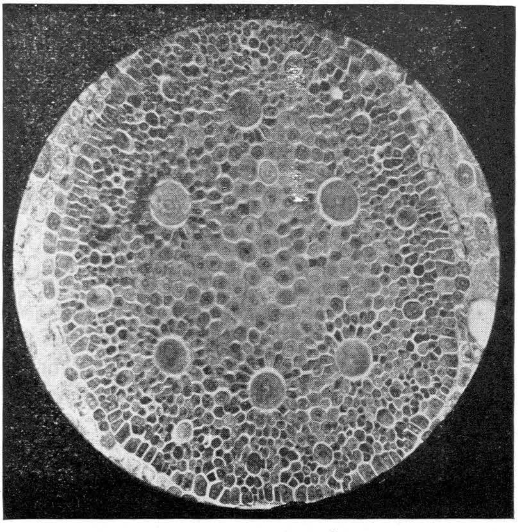
The embryo in a kernel of immature or moist corn usually changes from a light or creamy color before freezing to a dark or yellowish brown after freezing. The larger the percentage of moisture, the more sensitive the embryo to cold, and the more readily discoloration takes place. Corn containing 37 per cent moisture and frozen three days at 0° F. showed a slight embryo discoloration in three days and very pronounced darkening in six days after thawing. By looking over the notations regarding embryo color in Tables 5 to 12, it will be seen that the dark color is very closely correlated with loss of vitality. Generally where no loss of vitality resulted from the exposure to the cold, the embryo retained its normal color. The presence of both dark and light embryos on the same ear is associated usually with only a partial loss of vitality, and is frequently due to variation in moisture content of the kernels.

The practice of judging the germinative power of seed corn by the appearance of the embryo therefore seems justified. When loss of vitality has resulted from freezing, this seems to be a fairly safe guide. However, it seems possible that, in very exceptional cases, a loss of vitality might result from some other source without causing a discoloration of the embryo. The method, therefore, can hardly be said to take the place of a germination test.

EFFECT OF FREEZING ON EMBRYONIC TISSUES

Since ice is formed in kernels of immature corn when exposed sufficiently to freezing temperatures, often resulting in





Figs. 10 and 11—Micro-photographs of cross-sections of the primary root of frozen and unfrozen corn embryos respectively death, the effect of such ice formation upon the cell structure of the kernel embryo was studied. It was thought that such microscopic studies of frozen embryos might give some clue concerning the cause of death by freezing.

Figures 10 and 11 are microphotographs of cross sections of the primary root of frozen and unfrozen corn embryos respectively. The grain represented by Figure 10 had been frozen for 48 hours at a temperature of 5° F. below zero, and had a moisture content of 35 per cent. Figure 11 represents grain from the same ear which had not been frozen. A large number of frozen and unfrozen grains were sectioned and examined microscopically. No rupture of cell walls or other cytological effect of freezing and ice-formation within the kernels was apparent.

CHEMICAL EFFECTS OF FREEZING

Opportunity did not offer for an exhaustive study of chemical changes involved in freezing injury. However, an ordinary fodder analysis was made in triplicate of both frozen and unfrozen immature grain. A composite sample of shelled corn containing 37 per cent moisture was divided into two parts. One portion was dried immediately. The other was frozen for three days at a temperature of 0° F. At the end of three more days the embryos of the frozen grain had turned dark. This grain was dried and both samples analized. The results are given in Table 4. The differences recorded are probably within the limits of experimental error. Doubtless some chemical change has taken place, otherwise the tissues would not have darkened in color. A germination test of the frozen and unfrozen seed showed 0 and 100 per cent viability.

TABLE 4—*Composition of frozen and unfrozen seed corn*

Character of grain	Composition of moisture-free grain				
	Crude protein	Nitrogen-free extract	Fat	Crude fibre	Ash
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Unfrozen	13.13	78.65	4.54	2.30	1.38
Frozen	12.94	78.61	4.63	2.37	1.45
Ratio of unfrozen to frozen	.985	.999	1.02	1.03	1.05

These analyses were made under the direction of F. W. Upson, Station Chemist.

PROBABLE CAUSE OF DEATH FROM FREEZING

HISTORICAL REVIEW

There is no doubt but that plant tissues, under certain conditions, die as a result of freezing, but just what freezing does to the vital part of such tissues to bring about death is not fully understood. The theories which have been advanced to explain death by freezing seem to lack sufficient evidence to prove their correctness. Wide differences of opinion are held by various investigators regarding the direct cause of death. At the present time, therefore, any explanation of the phenomenon of death by freezing must be considered as an expression of the probable cause and not as a definite statement of what actually happens. The theories which have been advanced to explain the cause of death from freezing may be grouped as follows: (1) crushing of plant tissues, or rupturing of cell structures, (2) too rapid thawing, (3) desiccation of the protoplasm, (4) physical and chemical disorganization of the protoplasm and other cell contents.

CRUSHING OF PLANT TISSUES OR RUPTURING OF CELL STRUCTURES

As stated by Salmon (1917), the early observers of ice formation within plant tissues, knowing nothing of the cellular structure of plants, attributed death from freezing to rending or crushing of the tissues.

In 1737 Du Hamel and Buffon proposed that death resulted from a rupturing of the cell walls due to the expansion which accompanies ice formation. The same opinion was held by Geopert (1830) who discovered ice within the cells and also outside the cells in the intercellular spaces. Sachs (1860) found that ice was sometimes formed within the cells, and Müller-Thurgau (1886) concludes that ice is formed within the cells only in case of very large size, or very rapid freezing.

Supercooling followed by ice formation, and very rapid cooling are more injurious to plant tissues than slow cooling, according to Mez (1905). Neither supercooling nor rapid cooling give the water in the cells time to escape and ice is, therefore, formed within the cells. In each of the above cases where ice was formed within the cells, whether it was the result of slow or rapid cooling, or whether the tissues had been supercooled, the investigators seemed to think that the increase in volume probably worked some injury to the cell walls.

Plant tissues containing a large percentage of water, such as turgid leaves, and young, growing twigs are especially subject to injury from ice formation. Wiegand (1906) found the upper and lower parts of leaves entirely separated by layers of ice, and also the outer layers of twigs separated from the inner by a sheet of ice. The injury resulting from the freezing of green plants is due to the change in volume when the water in the plant freezes, according to Gassner and Grimme (1913), and not to any special effect upon the plant cells. The result of this increase in volume is a tearing of the tissues, or a breaking up of the cell structure. This form of injury is recognized by Chandler (1913) as being entirely possible, for he speaks of the tearing of tissues due to the tension developed at low temperatures.

While studying the influence of the temperature of liquid hydrogen on the germinative power of seeds, Thiselton-Dyer (1899) suggest that the sudden vacuum caused within the seeds by immersing them in liquid hydrogen might possibly produce physical ruptures which would weaken or destroy their vitality. Adams (1905) also mentions the possibility of injury from this source, but thinks the vacuum too small to be of any serious consequence. He concludes, further, that the intercellular spaces in seeds are very small, and that in moist seeds, after freezing has gone on for some time, these spaces become filled with a solid mass of ice. Then if the temperature is still further lowered, more ice is formed, and it is likely that complete rupture takes place, causing a separation of the cells from each other.

TOO RAPID THAWING

Many have thought that the phenomenon of death from freezing is not due directly to freezing but to the rate or rapidity of thawing. Sachs (1860) an early investigator, was an ardent supporter of this belief, and for many years his work was considered conclusive. Later, Müller-Thurgau (1886) pointed out inaccuracies in his work and showed by experiments with a large number of plants that there was no difference in the amount of killing whether tissues were thawed rapidly or slowly, except in the case of ripe apples and pears. It was found also by Molisch (1897) and Chandler (1913) that in general the rate of thawing is not related to the amount of killing at a given temperature, the exceptions to this rule being the leaves of lettuce, leaves of Agave americana, and ripe apples and pears. In arguing against the theory that plant tissues are killed by the rate of thawing rather than by freezing, Detmer (1893) mentions several mosses which can remain in a hard frozen condition for a long time without showing any material damage after thawing whether the latter process takes place slowly or suddenly.

Coming back again to the belief held by Sachs, it is stated by Adams (1905) that during the freezing process water is drawn from the cells and solidified in the intercellular spaces, and that if freezing has not gone too far, and if thawing be gradual, the ice melts and is absorbed again by the cells and no injury results. In discussing the effect of freezing on cultivated plants, Galloway (1895) makes a similar statement. Brown and Escombe (1897-1898) while trying to determine the influence of very low temperatures on the germinative power of seeds, express the opinion that the vitality of the seeds was injured more by rapid thawing than by gradual thawing.

DESICCATION OF THE PROTOPLASM

Probably the most generally accepted theory of the cause of death from freezing has been, that death results from desiccation of the protoplasm when water is drawn from the cells into the intercellular spaces in the process of ice formation. It was early discovered that when plant tissues freeze, water is drawn from the cells and ice crystals are formed in the intercellular spaces. Geoppert (1830) and Sachs (1860) both observed these phenomena but reached rather different conclusions as to the real cause of death. Geoppert thought that death resulted as a direct effect of freezing and that death occurred while the tissues were still in a frozen condition; while Sachs thought that death occurred during the thawing process. That water is withdrawn from the cells during the process of freezing and that ice crystals are usually formed in the intercellular spaces, and only rarely within the cells, was again declared by Müller-Thurgau (1886) and also by Molisch (1897); the latter observing the movement of water and the formation of ice crystals in plant tissues under the microscope. Both of these men were of the opinion that death from freezing is due to the withdrawal of water from the cells, and that it is essentially the same thing as death from desiccation. Müller-Thurgau went so far with his work as to determine the amount of water drawn from cells by freezing. For apple he found that at a temperature —13 degrees C., 63.7 per cent had been lost, and at —15.2 degrees C., 79.2 per cent of the water had passed from the cells.

In regard to the effect which the removal of water may have upon the cell contents, Wiegand (1906) thinks it is probable that death from freezing is caused by drying out of the protoplasm beyond the critical water content. Maximow (1908) agrees with Müller-Thurgau and Molisch in that the withdrawal of water during the freezing process is the killing factor. He concludes, however, that the withdrawal of water is limited to the plasma membrane, and that this membrane is the part of the cell which is injured and that as long as a film of water can be kept in contact with this membrane no injury takes place. Matruchot and Molliard (1901) also believed that water was drawn from the protoplasm and nuclear material of the cell in the process of freezing and that this continued until they contained less than the minimum required to maintain vitality. Protoplasm, in order to retain its vitality, according to Ewarts (1897), requires from 2 to 3 per cent of water. Adams (1905) contends that if these theories be true the same argument should hold for dry seeds which contain about 12 per cent of water. But dry seeds are not killed by freezing. Hence some other explanation must be found.

PHYSICAL AND CHEMICAL DISORGANIZATION OF THE PROTOPLASM AND OTHER CELL CONTENTS

Many who have sought to determine the cause of death by freezing have concluded that freezing produces certain physical and chemical changes in the protoplasm and other cell contents, and that these changes result in death of the living matter. In harmony with this view, Detmer (1893) states, "In consequence of the disorganization of the protoplasm the cellular fluids leave the plasma; at the same time the nature of the hyloplasmic layers undergoes a complete change and they are now pervious to many substances which in a normal condition they did not permit to pass. This is the cause of the discoloration of frozen plants and of the phenomenon that pieces of frozen red beet, if put into water, readily part with coloring matter and sugar. while the living cells tenaciously retain these substances." Becquerel (1905), in studying the action of liquid air on the life of seeds, found that if sufficient moisture was present in the tissues the cold disorganized the protoplasm and nucleus, making germination impossible. Galloway (1895) also contributed to this same idea, for he concluded that a freezing temperature may be sufficiently low to cause a chemical disorganization of the living substance and that the part of the plant where this takes place dies. Gorke (1906) and Schaffnit (1912) both found that freezing precipitated certain proteids from the cell sap and that the ease with which these proteids are precipitated bears some relation to the hardiness of the plant. Precipitation of the proteids, therefore, according to their interpretations, is the cause of death. Chandler (1913), however, does not agree with this. He found no precipitation of proteids in the sap of young twigs of apple, plum, or pear and only slight traces of it in other plants. He calls attention to the fact, however, that frozen plant tissues, soon after thawing, take on a brown color and a soft watery condition, and that evaporation goes on much more rapidly from the surface of such tissues than it does from the surface of similar tissues which have not been frozen.

PERSONAL INTERPRETATION

One of the objects of the experiments reported in this bulletin was to determine the effect of freezing upon the cellular structure of the corn kernel and especially of the embryonic tissues, for the purpose of indicating the true cause of death resulting from freezing. It was thought that if death was due to some mechanical injury to the tissues or to disorganization of the cellular material, it would be indicated by a separation of the cells from each other, or by broken down cell walls, or by a difference in the appearance of the cell contents. With this idea in mind, careful studies were made both of frozen and unfrozen sections of embryonic material, permanently mounted and stained sections being used. Mechanical injuries of the cell structure or rupturing of the tissues were sought for with considerable care, as it was thought that these probably were the primary causes of the loss of vitality.

No such injuries were found, however, in the embryonic tissues of the kernel. It was thought, then, that if such injuries result at all from freezing, they should occur in the tender tips and stems of young corn seedlings. Sections of frozen tips and stems of such material were, therefore, studied. Even in this tender, rapidly growing material no rupturing or breaking down of the cellular structure could be detected. However, from the observations of Wiegand (1906), Chandler (1913), and others, there can be no doubt but that a rupturing of plant tissues sometimes results from freezing; but from the evidence at hand, it must be concluded that death from freezing is not due to mechanical injuries but to some other cause.

The protoplasmic and nuclear material of the cells of frozen and unfrozen tissues were studied microscopically; the same material being used for this as was used while searching for mechanical injuries. So far as was observed, no disorganization or change of appearance was detected. It should be stated here, however, that observations of the cellular material were not very extensive, and the material used for study had been placed in the killing and fixing solution while still in a frozen condition. It is probable, therefore, that killing took place before there could be any material readjustment of the living matter. It was thought, however, that the change in color of embryonic tissues and other plant tissues and the soft watery condition characteristic of all tissues which have been frozen to death indicates that some physical or chemical change has been brought about. Even tho the change in color of the embryo of a corn kernel after freezing may be due to the action of some enzyme or of bacteria, the fact remains that a change has been effected which makes possible such action. The instance cited by Detmer (1893) of pieces of frozen red beet giving up their coloring matter and sugar when placed in water, while these substances are tenaciously retained by the unfrozen material, adds some evidence of a physical or chemical change. The soft, watery condition of plant tissues after freezing also appears to be the result, at least in part, of disorganization of the cellular material, and not entirely to a withdrawal of the water from the cells. That this is true is drawn from the observations of Müller-Thurgau (1886) and Mez (1905) regarding the formation of ice within the cells when the tissues are supercooled or frozen rapidly. If the extraction of water from the cells was the only cause of the watery condition in question, tissues which are frozen rapidly or supercooled, so that crystalization takes place largely in the cells, should not exhibit this condition. But this water-soaked condition is characteristic of frozen tissues whether the freezing has been done rapidly or slowly.

Altho chemical changes have not been established by chemical analysis, it seems certain that changes take place within the protoplasmic and nuclear contents as a result of freezing and that these changes make it impossible for the processes of life to continue.

The withdrawal of water from the cells by freezing has been considered by many as the cause of death. It was noted that in moist corn kernels, water was withdrawn from the tissues and ice formed in masses and sheets in space surrounding or separating different tissues, and that death usually accompanied such ice formation. It was also noted that air-dry corn, which contains from 10 to 12 per cent of moisture, was not frozen, at least its vitality was not injured, and according to the observations of Brown and Escombe (1897-8), Adams (1905), Thiselton-Dyer (1899), and others it was not injured even when exposed for several hours to the temperature of liquid air or liquid hydrogen. According to Müller-Thurgau (1886), apples lost 63.8 per cent of their moisture when frozen at —4.5 degrees C.; 36.2 per cent of the total water, therefore, remained in the cells. Kernels of corn which contain a large percentage of water will freeze at this temperature and die. If the moisture content of the cells of a kernel of corn were reduced to 30 or even 20 per cent at this temperature, the vitality should remain uninjured, so far as moisture is concerned. Dry seeds contain only 10 to 12 per cent of moisture, yet they retain their vitality, and a still further reduction in the moisture content can be made without injury. Ewarts (1897) shows that the fatal minimum moisture content of protoplasm is 2 or 3 per cent. The theory is, then, that as the cooling goes on, more and more water is withdrawn until less than this amount remains in the cell, and death results. This should also hold true for dry seed which contain 10 or 12 per cent of water, but these are not injured by such freezing. An example may also be taken from Table 9, where corn containing 20.5 per cent of moisture was entirely killed, while corn containing 16.3 per cent of moisture showed no injury. The freezing evidently did not reduce the moisture content in the former case more than 2 or 3 per cent, yet the vitality was destroyed. It does not seem probable that the removal of so small an amount of water would cause death. It seems more probable, however, that the small difference in moisture content was sufficient to permit disorganization of the protoplasm in the one case, while in the other it remained unaffected.

The rate of thawing and its relation to killing was not studied. The results which have been obtained and reported by Müller-Thurgau (1886), Molisch (1897), and Chandler (1913) seem to indicate quite clearly that it has very little to do with the amount of killing. It can hardly be considered, therefore, as an important factor in bringing about the death of frozen tissues.

EFFECTS OF FREEZING UPON THE VIABILITY OF SEED CORN

Ordinary freezing temperatures do not injure mature, dry corn, but it is always the immature or damp corn that is injured by freezing. It was proposed, therefore, to determine at what temperature freezing and loss of vitality take place in corn at different stages of maturity as indicated by differences in moisture content.

The effect of freezing upon the germinative qualities of seed corn has been tested experimentally under two sorts of conditions: (1) Artificial freezing under control conditions; and (2) natural freezing of corn standing in the field under prevailing natural conditions.

VITALITY OF CORN FROZEN UNDER CONTROL CONDITIONS

APPARATUS

The low temperatures used in these experiments were secured under control conditions by the use of a freezing mixture of salt and ice. By mixing the salt and ice in the proportion of one part of salt to two parts of ice a temperature of —5° F. was secured. In order to secure the various ranges of temperature and to maintain those temperatures for several hours, two different devices were used.

For temperatures above zero, an insulated freezing box was made. The essential parts of this box are: (1) A compartment for containing the freezing mixture. This was large enough to hold about two hundred pounds of crushed ice. (2) A compartment for containing a strong salt solution and a freezing cell. This compartment or chamber was large enough to hold twenty gallons of brine. (3) A freezing cell into which the material was put for freezing. This cell was cylindrical in shape, 5 inches in diameter and 18 inches deep, with capacity for sections from 30 ears of corn. (4) A series of connected cells in the freezing mixture compartment. This series of cells was connected with the brine chamber in such a way as to allow the cells to fill with brine. (5) A pump for circulating the brine thru the cells and back into the brine chamber. (6) A thermometer to indicate the temperature in the freezing cell.

The working principle of this device was somewhat as follows: The freezing mixture of salt and ice was packed around the series of brine cells. This reduced the temperature to 0° F. or below in this chamber, and cooled the brine in the cells. The brine was made strong enough so that it would not freeze at this temperature. The corn was then placed in the freezing cell, the lid closed, and the thermometer inserted. When all was ready, the pump, operated by an electric motor, was started and the chilled brine from the series of cells was forced into the large brine chamber and other brine drawn into the cells to cool. By this method the twenty gallons of brine was gradually cooled to the desired temperature. As soon as the desired temperature was secured, the pump was stopped. The large volume of brine which surrounded the freezing cell maintained a comparatively even temperature in the latter for several hours.

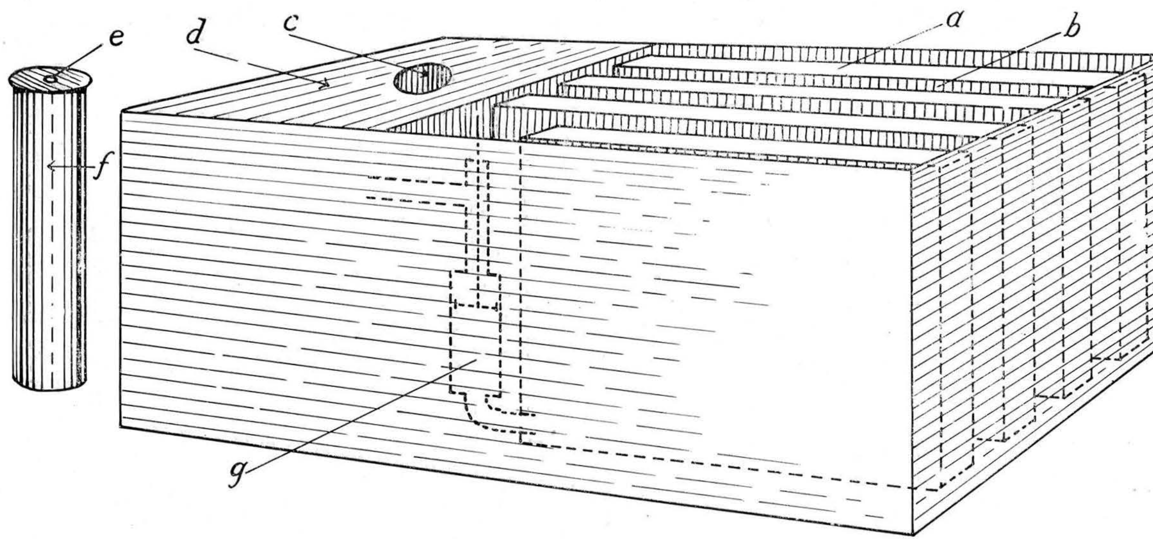


Fig. 12—Freezing apparatus

a. Connected cells in which salt solution circulates
b. Spaces between cells where freezing mixture is placed
c. Place where freezing cell is inserted
d. Compartment containing salt solution
e. Lid with hole for inserting thermometer
f. Freezing cell
g. Pump for circulating salt solution

PROPERTIES OF SOLUTION OF SALT—*From J. E. Siebel, Compend of Mechanical Refrigeration and Engineering*

Percentage of salt by weight	Pounds of salt per gallon of solution	Weight per gallon 39°F.	Freezing point Fahrenheit
	(Pounds)	*(Pounds)*	*(Degrees)*
0	0	8.35	32
1	0.084	8.40	30.5
2	0.169	8.46	29.3
2.5	0.212	8.50	28.6
3	0.256	8.53	27.8
3.5	0.300	8.56	27.1
4	0.344	8.59	26.6
5	0.433	8.65	25.2
6	0.523	8.72	23.9
7	0.617	8.78	22.5
8	0.708	8.85	21.2
9	0.802	8.91	19.9
10	0.897	8.97	18.7
12	1.092	9.10	16.0
15	1.389	9.26	12.2
20	1.928	9.64	6.1
24	2.376	9.90	1.2
25	2.488	9.97	0.5
26	2.610	10.04	—1.1

For securing the temperatures below zero a different sort of device was used. This consisted simply of a barrel with a small keg placed inside of it. The space around the keg was filled with sawdust. The freezing cell from the other apparatus was placed in the keg and the freezing mixture packed around it until the keg was full. It was then covered well with burlap and a tight lid put on the barrel. By this method a temperature of —5° could be maintained almost constant in the freezing cell thruout the twenty-four hours.

After the corn was frozen it had to be dried quickly in order to keep it from becoming mouldy. A screen wire box was, therefore, provided in which the corn could be cured. This box was placed in a warm, dry room and near a south window where the breeze could strike it. This arrangement was found to be satisfactory, as the corn dried within a few days.

SELECTION OF MATERIAL

In order to facilitate the selection of material for the freezing tests, four plots of corn were planted. The first one was planted early and the other three at successive intervals of ten days each. The same variety of corn (Hogue's Yellow Dent) was used for each planting. Thus ears of the same variety but of different degrees of maturity could easily be selected at any one time in the fall. As soon as the early planted corn was well matured, selections were made from each plot. These selections included ears representing four stages of maturity. The first stage was green corn, much greener than would ever be selected for seed. In fact, this represented the "roasting ear" stage of development. The ears of the fourth stage were the most mature ones that could be found in the field at the time. The starchy part of the kernels was beginning to appear dry and mealy when cut with a knife. The horny part of the kernels also had begun to appear hard and brittle. As the season advanced, the corn secured for the fourth stage became drier and more mature, while the selections for the first stage remained very much the same thruout the season. The second and third stages represented intermediate degrees of maturity between the first and the fourth.

METHOD OF HANDLING

The ears selected were taken at once from the field and treated in the following manner: (1) A part of the tip was removed and discarded. (2) Each ear was divided into three sections. The section next to the tip was used for a moisture test, and the adjacent section for an immediate freezing test. The remaining part of the ear was stored in a dry, airy place where it would have a chance to cure thoroly. This part together with the frozen section was kept in storage for four or five months. At the end of that time germination tests were made.

MOISTURE TESTS

Moisture tests were made of the grain on each ear. The samples were dried at 100° to 110° C., and the percentage of water was calculated, using the green weight as a basis. In all cases the sample for the moisture determination was taken next to, or from the part of the ear which was to be subjected to the freezing temperature. The percentage of moisture thus secured represented very closely the actual moisture content of the corn placed in the freezing test.

SUBJECTION TO FREEZING TEMPERATURES

Ears representing the four stages of maturity were subjected to different ranges of freezing temperature for a period of twenty-four hours. That is, one lot of ears consisting of four or five from each stage of maturity was subjected to a temperature ranging from 28° to 32° F. A similar lot was subjected to a range from 20° to 24° F.; another from 12° to 16° F.; another from 4° to 8° F.; and still another from —5° to 0° F. The ears were placed in the freezing chamber within an hour or two after being brought from the field. The temperature was then lowered to the desired degree as quickly as possible. For the higher temperature and for the range below zero, from one to two hours were required, while for the intermediate temperatures three to four hours were required. The difference in length of time was due to the difference in the degree of cold and in the apparatus used. After exposure to the cold, no attempt was made to bring the corn gradually to a higher temperature, but it was removed from the freezing chamber and exposed at once to the air temperature. It was then placed in a screen wire box which was set in a warm, dry, airy place. Here the ears dried quickly, so that but little loss from damp or mouldy seed was experienced. All freezing tests except those in a special experiment in 1916 were made with ear corn from which the husks had been removed.

GERMINATION

After the samples had been subjected to freezing temperatures and had remained in storage until thoroly cured, germination tests were made from each section. The corresponding section from the same ear which had not been exposed to the freezing temperature was placed in germination test at the same time. The percentage germination of the latter serves as a standard with which the germinative ability of the exposed part may be compared, or by which the effect on vitality of exposure to the low temperatures may be measured.

The germination tests were made between blotting papers on moist sawdust. Wet burlap was used as a covering over the blotting paper. The germination boxes were placed in a warm incubator having a temperature of 30° C. and allowed to remain for six days, when the counts were made. The germination percentages unless otherwise stated mean perfect germination with prospects for normal development.

OBSERVATION OF ICE IN SEED

Because of the supposed relation between the formation of ice within plant tissues and death by freezing, observations were made regarding the temperature at which freezing actually occurs in corn containing different amounts of moisture. By freezing is meant here, the formation of ice crystals within the kernel. The observation was made by cutting thru the small end of the kernel, and by scraping the cut surface, or by digging in and around the embryo with a knife. The observation was made immediately after removing the sample from the freezing chamber.

The occurrence of ice crystals was not noted in all of the tests. In those tests where notes were taken all of the ears were examined. In the tables, the presence or absence of ice in all cases where examinations were made is indicated. It was very difficult to detect the ice in the samples of low moisture content because of the small amount present and because of rapid thawing. There is a possibility, therefore, that ice crystals may have been present in some of the samples and yet escaped detection. The presence of ice is discussed in connectoin with the following investigations.

COLOR OF EMBRYO

Notes were also taken regarding the color of the embryo at the time when the germination tests were made. The color was designated as either dark or light. The light color represents the natural color of a normal embryo. On the other hand, a dark or brownish color is quite characteristic of a frozen embryo. In a number of cases a part of the kernels on an ear would have a dark embryo and part of them a light embryo. Usually this condition was found to be associated with only a partial loss of vitality.

For convenience of comparison, all ears which were subjected to a given range of temperature are grouped in the tables according to moisture content, a range of 5 per cent being allowed for each group. In all cases where there were more than one sample in a given moisture range an average for the group is given.

RELATION BETWEEN MOISTURE CONTENT AND INJURY AT VARIOUS DEGREES OF FREEZING

FREEZING AT TEMPERATURE RANGE OF 32° TO 28° F.

The data for all the samples frozen at the temperature range of 32° to 28° F. are given in Table 5. It would seem from the data in this table that the vitality of corn with a high moisture content may be seriously injured or almost totally destroyed by such a light freezing as is represented by the above temperature range when prolonged for a period of 24 hours.

TABLE 5—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
80 to 85..	84.3	0	0	0:0	*	Dark
	80.7	0	0	0:0	*	Dark
Average..	82.5	0	0	0:0		
70 to 75..	72.1	100	0	100:0	Ice	Dark
	71.8	100	0	100:0	Ice	Dark
	71.0	100	0	100:0	*	Dark
Average..	71.9	100	0	100:0		
65 to 70..	69.2	20	0	100:0	*	Dark
	69.2	100	0	100:0	*	Dark
	68.4	100	0	100:0	*	Dark
	68.3	87	0	100:0	Ice	Dark
	67.2	100	20	100:20	*	Dark
	66.5	100	0	100:0	Ice	Dark
	66.2	100	0	100:0	Ice	Dark
	65.2	100	0	100:0	*	Dark
Average..	67.5	88.4	2.5	100:2.8		
60 to 65..	62.8	100	0	100:0	*	Dark
	61.1	100	0	100:0	*	Dark
Average..	62.0	100	0	100:0		
55 to 60..	59.7	100	50	100:50	*	*
	57.7	100	0	100:0	*	Dark
	56.6	100	30	100:30	*	Light
	55.2	87	37	100:43	Ice	Dark and light
Average..	57.6	96.8	29	100:31		
50 to 55..	54.7	90	75	100:80	Ice	Dark and light
	54.0	100	0	100:0	*	Dark
	53.9	100	0	100:0	Ice	Dark
	52.3	100	87	100:87	Ice	Dark and light
	51.2	100	0	100:0	Ice	Dark
Average..	53.2	98	32.4	100:33		

*No observations made.

TABLE 5 *(Continued)—Effect of freezing temperature on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
40 to 45..	45.8	100	100	100:100	*	*
	44.1	100	100	100:100	*	*
	44.1	100	40	100:40	*	Dark
	44.0	100	40	100:40	*	Dark
	42.4	75	50	100:67	None	Light
Average..	44.1	95	66.0	100:69		
35 to 40..	39.5	100	55	100:55	*	Light
	38.9	100	20	100:20	*	Dark
	38.7	60	60	100:100	*	Light
	38.6	100	50	100:50	*	*
	37.1	100	58	100:58	*	Light
	36.3	100	80	100:80	*	Light
	36.1	100	85	100:85	None	Light
	35.9	100	87	100:87	None	Light
	35.8	100	100	100:100	*	Light
	35.6	100	100	100:100	*	*
	35.1	100	100	100:100	*	Light
Average..	37.1	96.4	65	100:71		
30 to 35..	33.7	100	100	100:100	*	*
	33.1	90	35	100:39	None	Light
	30.6	100	100	100:100	*	Light
	30.3	100	60	100:60	*	Dark and light
Average..	31.9	97.5	73.8	100:75		
25 to 30..	28.3	100	100	100:100	*	*
	28.2	100	80	100:80	*	Light
	28.1	60	60	100:100	*	Dark
	27.8	100	100	100:100	*	Light
	27.3	100	87	100:87	None	Light
	27.3	80	80	100:100	*	Light
	26.4	100	20	100:20	*	Dark and light
	25.7	100	100	100:100	*	Light
Average..	27.4	92.5	78.4	100:85		

*No observations made.

TABLE 5 *(Continued)—Ewect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Tempera ure range 32° to 28°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25..	21.4	100	100	100:100	*	*
	21.2	100	100	100:100	*	Light
	20.3	100	100	100:100	*	*
	20.1	100	100	100:100	*	Light
Average..	20.8	100	100	100:100		

*No observations made.

The ears with the lowest moisture content were uninjured, while many of those of intermediate moisture content showed more or less loss of vitality. It will also be noted that ice crystals were found in the kernels containing 50 per cent or more of moisture, while no ice was noted in kernels containing less than this amount.

All kernels with high moisture content showed dark embryos. The change in embryo color and in ice formation to no ice, together with the germination tests, seems to indicate that the transition from a critical moisture content to one where little or no injury resulted took place between 50 and 40 per cent.

TEMPERATURE 24° TO 20° F.

Table 6 contains the data for all the freezing tests in which the temperature ranged from 24° to 20° F. The same observations were made as for the previous range of temperature. By comparing the germination of the normal and of the frozen grain in this table with those in Table 5, it may be seen that the exposure to this range of temperature is fatal to corn of lower moisture content than was the temperature of 32° to 28° F. Even corn containing as low as 26 per cent of moisture showed some ice. Discoloration of embryo is more pronounced, and the transition from a fatal moisture content to one not fatal seems to have occurred between 35 and 28 per cent.

TABLE 6—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 24° to 20°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
75 to 80..	79.0	100	0	100:0	*	Dark
	76.5	100	0	100:0	*	Dark
	75.9	62	0	100:0	Ice	Dark
	75.7	75	0	100:0	Ice	Dark
Average..	76.8	84.2	0	100:0		
70 to 75..	73.5	100	0	100:0	*	Dark
	70.6	87	0	100:0	Ice	Dark
	70.2	100	0	100:0	*	Dark
Average..	71.4	95.7	0	100:0		
65 to 70..	68.8	100	0	100:0	Ice	Dark
60 to 65..	61.5	100	0	100:0	Ice	*
	60.4	100	0	100:0	Ice	Dark
Average..	61.0	100	0	100:0		
55 to 60..	58.9	100	0	100:0	*	Dark
	58.6	100	0	100:0	*	Dark
	57.4	100	0	100:0	Ice	Dark
Average..	53.3	100	0	100:0		
50 to 55..	53.9	100	0	100:0	Ice	Dark
	51.3	100	12	100:12	Ice	Dark
Average..	52.6	100	6.0	100:6		
45 to 50..	49.6	100	25	100:25	Ice	*
	45.1	100	0	100:0	Ice	Dark
Average..	47.4	100	12.5	100:12		
40 to 45..	43.1	100	25	100:25	Ice	*
	44.9	100	0	100:0	Ice	Dark
	42.4	100	37	100:37	Ice	Dark and light
	42.0	100	0	100:0	*	Dark
	41.7	100	0	100:0	*	Dark
	41.0	100	12	100:12	Ice	Dark
Average..	42.5	100	12.3	100:12		

*No observations made.

TABLE 6 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 24° to 20°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
35 to 40..	40.0	100	0	100:0	Ice	*
	39.4	100	0	100:0	*	Dark
	35.5	100	40	100:40	*	Light
Average..	38.3	100	13	100:13		
30 to 35..	33.8	100	0	100:0	*	Dark
	30.9	100	100	100:100	None	*
	30.7	100	100	100:100	None	*
Average..	31.8	100	66.6	100:67		
25 to 30..	28.8	100	20	100:20	*	Dark
	28.8	100	75	100:75	Ice	Dark
	28.3	100	50	100:50	Ice	Dark and light
	27.5	100	100	100:100	None	*
	27.4	100	100	100:100	*	Light
	27.1	100	100	100:100	*	Light
	26.2	87	87	100:100	Ice	Light
Average..	27.7	98.1	76.0	100:77		
20 to 25..	22.6	100	100	100:100	*	Light
	22.1	100	87	100:87	None	Light
	20.4	100	100	100:100	None	*
Average..	21.7	100	95.7	100:96		
15 to 20..	17.0	100	100	100:100	*	Light

*No observations made.

TEMPERATURE RANGE 16° TO 12° F.

The data for the corn subjected to a temperature ranging from 16° to 12° F. are given in Table 7. It will be noted from this table that the fatality range is very much the same as for the temperature of 24° to 20° F., but runs somewhat lower. Samples containing 33 per cent or more of moisture were killed by the 24-hour exposure to this range of temperature; the embryo generally showed a dark color, and ice formation was

TABLE 7—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 16° to 12°F.

Moisture range	Moisture in grain	Germination: Normal grain	Germination: Frozen grain	Germination: Ratio of normal to frozen	Ice observed in grain	Embryos dark or light
Per cent	*Per cent*	*Per cent*	*Per cent*			
65 to 70..	67.2	100	0	100:0	Ice	*
60 to 65..	61.8	100	0	100:0	*	Dark
55 to 60..	60.0	100	0	100:0	Ice	*
50 to 55..	54.6	100	0	100:0	*	Dark
45 to 50..	48.9	100	0	100:0	*	Dark
	47.7	100	0	100:0	Ice	*
	48.5	100	0	100:0	*	Dark
	47.6	100	0	100:0	*	Dark
	46.2	100	0	100:0	*	Dark
Average..	48.0	100	0	100:0		
40 to 45..	44.5	80	0	100:0	*	Dark
35 to 40..	39.6	100	0	100:0	*	Dark
	38.5	100	0	100:0	*	Dark
	36.8	100	0	100:0	*	Dark
	35.9	75	0	100:0	Ice	*
Average..	37.7	93.8	0	100:0		
30 to 35..	34.6	100	0	100:0	*	Light
	34.1	100	0	100:0	Ice	*
	33.2	100	0	100:0	*	Dark
	31.5	100	60	100:60	*	Dark and light
	31.2	100	0	100:0	Ice	*
Average..	32.9	100	12.0	100:12		
25 to 30..	29.7	100	20	100:20	*	Dark and light
	28.9	100	0	100:0	*	Light
	26.5	100	100	100:100	*	Light
	26.4	100	60	100:60	*	Dark and light
	26.4	100	60	100:60	*	Light
	26.1	100	0	100:0	None	*
	26.0	100	0	100:0	*	Dark
Average..	27.1	100	34.3	100:34		

*No observations made.

TABLE 7 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 16° to 12°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25..	24.4	100	40	100:40	*	Light
	23.9	100	100	100:100	*	Light
	22.7	100	100	100:100	*	Light
	22.1	100	100	100:100	*	Light
	21.5	100	100	100:100	*	Light
	21.4	100	100	100:100	*	Light
	21.0	100	100	100:100	*	Light
	20.8	100	100	100:100	*	Light
	20.8	100	50	100:50	None	*
Average..	22.1	100	87.8	100:88		
15 to 20..	19.8	100	100	100:100	*	Light
	18.1	100	100	100:100	*	Light
	17.8	100	100	100:100	*	Light
	17.2	100	100	100:100	*	Light
	17.0	100	100	100:100	*	Light
	15.5	100	100	100:100	*	Light
	15.3	100	100	100:100	*	Light
Average..	17.2	100	100	100:100		

*No observations made.

noted thruout the range. The transition here from a fatal moisture content to one free from injury seems to have occurred between 30 and 25 per cent. Below this range, no definite injury appears to have resulted from the exposure as indicated by the percentage germination or by the color of the embryo.

TEMPERATURE RANGE 8° TO 4° F.

The data for the freezing tests in which a range of temperature from 8° to 4° F. was used are given in Table 8. In these tests, freezing and loss of germinative ability took place at a lower moisture content than in any of the previous tests. The transition here from injury to no injury seems to have occurred between 25 and 19 per cent moisture content, and but little loss of vitality appears to have resulted where the corn contained less than 20 per cent of moisture.

TABLE 8—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 8° to 4°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
50 to 55..	52.6	30	0	100:0	Ice	*
	51.5	100	0	100:0	Ice	*
Average..	52.1	65	0	100:0		
40 to 45..	41.7	55	0	100:0	Ice	*
35 to 40..	37.7	100	0	100:0	Ice	*
30 to 35..	31.2	100	0	100:0	Ice	*
25 to 30..	29.5	75	0	100:0	Ice	*
	27.4	100	20	100:20	*	Dark
	26.9	100	0	100:0	Ice	*
Average..	27.9	91.7	6.6	100:7		
20 to 25..	24.8	100	100	100:100	*	Light
	22.9	100	0	100:0	Ice	*
	21.0	100	40	100:40	*	Dark and light
Average..	22.9	100	46.6	100:47		
15 to 20..	19.4	100	100	100:100	*	Medium dark
	19.3	100	80	100:80	*	Dark and light
	18.5	100	100	100:100	*	Medium dark
	17.7	100	100	100:100	*	Light
	17.6	100	100	100:100	*	Light
	16.4	100	100	100:100	*	Light
	16.0	100	100	100:100	*	Light
	15.7	100	100	100:100	*	Medium dark
Average..	17.6	100	97.5	100:98		
10 to 15..	14.8	100	100	100:100	*	Light
	14.7	100	100	100:100	*	Light
	14.1	100	100	100:100	*	Light
	13.8	100	100	100:100	*	Light
	13.7	100	100	100:100	*	Light
	13.2	100	100	100:100	*	Light
	13.0	100	100	100:100	*	Light
	11.7	100	100	100:100	*	Light
	10.8	100	100	100:100	*	Light
Average..	13.5	100	100	100:100		

*No observations made.

TEMPERATURE RANGE 0° TO —5° F.

The notes on the corn subjected to a temperature of 0° to —5° F. are compiled in Table 9. It will be observed here that the injury resulting from exposure to this temperature occurred in those ears having a moisture content greater than 16 per cent. Below that, little or no injury resulted. The transition seems to have occurred between 20 and 18 per cent. Loss of viability or power of germination occurred here with a slightly smaller percentage of moisture than at the temperature of 8° to 4° F. Ice crystals were found in the kernels from a few ears in which the moisture content was as low as 20 per cent. However, little or no loss of viability occurred in ears containing 16 per cent or less of moisture.

TABLE 9—*Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 0° to —5°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
65 to 70..	67.8	100	0	100:0	Ice	Dark
60 to 65..	60.4	100	0	100:0	Ice	Dark
55 to 60..	59.6	100	0	100:0	Ice	Dark
	59.2	100	0	100:0	Ice	Dark
Average..	59.4	100	0	100:0		
50 to 55..	51.1	100	0	100:0	Ice	Dark
	50.3	100	0	100:0	Ice	Dark
Average..	50.7	100	0	100:0		
45 to 50..	49.7	100	0	100:0	Ice	Dark
	48.8	100	0	100:0	*	Dark
	48.5	100	0	100:0	Ice	Dark
	48.2	100	0	100:0	*	Dark
	46.8	100	0	100:0	Ice	Dark
	45.9	100	0	100:0	*	Dark
	45.6	100	0	100:0	Ice	Dark
	45.4	100	0	100:0	Ice	Dark
	45.3	100	0	100:0	*	Dark
	45.2	100	0	100:0	Ice	Dark
Average..	46.9	100	0	100:0		
40 to 45..	43.6	100	0	100:0	Ice	Dark
	43.3	100	0	100:0	*	Dark
	42.3	100	0	100:0	Ice	Dark
	41.0	100	0	100:0	Ice	Dark
	40.9	100	0	100:0	*	Dark
	40.7	100	0	100:0	Ice	Dark
	40.2	100	0	100:0	Ice	Dark
Average..	41.7	100	0	100:0		

*No observations made.

TABLE 9 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range C° to —5°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
35 to 40..	40.0	100	0	100:0	*	Dark
	40.0	100	0	100:0	*	Dark
	39.9	100	0	100:0	Ice	Dark
	39.8	100	0	100:0	*	Dark
	39.5	100	0	100:0	Ice	Dark
	39.5	100	0	100:0	Ice	Dark
	39.1	100	0	100:0	*	Dark
	38.8	100	0	100:0	*	Dark
	38.8	100	0	100:0	*	Dark
	38.4	100	0	100:0	Ice	Dark
	37.9	100	0	100:0	Ice	Dark
	37.7	100	0	100:0	Ice	Dark
	37.7	100	0	100:0	*	Dark
	36.8	100	0	100:0	Ice	Dark
	35.1	100	0	100:0	Ice	Dark
Average..	38.6	100	0	100:0		
30 to 35..	33.8	100	0	100:0	*	Dark
	33.1	100	0	100:0	Ice	Dark
	31.1	100	0	100:0	*	Dark
	30.4	80	0	100:0	Ice	Medium dark
	30.1	100	0	100:0	Ice	Dark
Average..	31.7	96	0	100:0		
25 to 30..	30.0	100	0	100:0	Ice	Dark
	28.7	100	0	100:0	*	Dark
	27.6	100	0	100:0	*	Dark
	26.7	100	0	100:0	*	Dark
	26.6	100	0	100:0	Ice	Dark
	25.9	100	0	100:0	*	Medium dark
	25.2	100	0	100:0	Ice	Light
	25.2	100	0	100:0	*	Dark
Average..	27.0	100	0	100:0		

*No observations made.

TABLE 9 *(Continued)—Effect of freezing temperatures on germination of corn differing in moisture content (1913 and 1914)*

Temperature range 0° to —5°F.

Moisture range	Moisture in grain	Germination			Ice observed in grain	Embryos dark or light
		Normal grain	Frozen grain	Ratio of normal to frozen		
Per cent	*Per cent*	*Per cent*	*Per cent*			
20 to 25..	24.8	100	0	100:0	Ice	Dark
	24.5	100	0	100:0	None	Dark
	24.4	100	0	100:0	*	Dark
	22.3	100	0	100:0	None	Light
	21.5	100	0	100:0	*	Dark
	21.2	100	0	100:0	*	Medium dark
	20.5	100	0	100:0	Ice	Dark
Average..	22.7	100	0	100:0		
15 to 20..	20.0	100	20	100:20	None	Dark and light
	19.9	100	0	100:0	Ice	Dark and light
	18.9	100	60	100:60	*	Light
	18.4	100	20	100:20	*	Medium dark
	16.3	100	100	100:100	None	Light
	15.6	100	100	100:100	None	Light
	15.5	100	100	100:100	*	Light
	15.3	100	100	100:100	None	Light
Average..	17.5	100	62.5	100:63		
10 to 15..	14.8	100	100	100:100	*	Light
	14.4	100	80	100:80	*	Light
	14.3	100	100	100:100	*	Light
	13.6	100	100	100:100	None	Light
	13.0	100	100	100:100	None	Light
	11.9	100	100	100:100	None	Light
Average..	13.7	100	96.6	100:97		

*No observations made.

SUMMARY OF GERMINATION TESTS UNDER CONTROLLED CONDITIONS

A summary of the average germinations of corn exposed to the different ranges of temperature, and containing various amounts of moisture, is given in Table 10. The data in this table are taken from the detail tables for the different temperature ranges. It will be noted from this table that (1) as the moisture content of the corn diminishes, the injury (with some

TABLE 10—*Summary showing effect of various freezing temperatures on germination of corn differing in moisture content (1913-1914)*[1]

Per cent moisture in grain	Temperature ranges (degrees F.)				
	32 to 28	24 to 20	16 to 12	8 to 4	0 to —5
	Germination per cent	Germination per cent	Germination per cent	Germination per cent	Germination per cent
80 to 85....	0	0	...	...	..
75 to 80....	0	0	...	...	..
70 to 75....	0	0	...	...	..
65 to 70....	3	0	0	...	0
60 to 65....	0	0	0	...	0
55 to 60....	31	0	0	...	0
50 to 55....	33	6	0	0	0
45 to 50....	...	12	0	...	0
40 to 45....	69	12	0	0	0
35 to 40....	71	13	0	0	0
30 to 35....	75	67	12	0	0
25 to 30....	85	77	34	7	0
20 to 25....	100	96	88	47	0
15 to 20....	...	100	100	98	63
10 to 15....	...	...	...	100	97

[1]This table is compiled from the averages found in Tables 5 to 9. The given temperatures were continued for a period of twenty-four hours.

irregularity) to the vitality of the kernel from exposure to any given temperature becomes less; (2) in the case of immature corn, freezing injury at a given moisture content increases as the temperature lowers; and (3) the vitality of corn with a moisture content ranging from 10 to 14 per cent is not injured by exposure to temperature of 0° to —5° F. for a period of 24 hours. For corn containing 20 to 25 per cent moisture, the germination percentages, when exposed to the temperature ranges of 32° to 28° F., 24° to 20° F., 16° to 12° F., 8° to 4° F., and 0° to —5° F., were respectively 100, 96, 88, 47, and 0 per cent.

EFFECT OF FREEZING ON DRY CORN

In 1911, freezing tests were made with corn which had been cured one month in a dry room, and also with corn cured three months. The grain at the time of freezing contained from 12 to 14 per cent moisture. The results of these tests are shown in Table 11. Practically no loss of vitality resulted in either case, even at the lowest temperature.

TABLE 11—*Effect of freezing temperatures on the germination of corn which had been cured in a dry room before freezing (1911). Moisture range in grain 12 to 14 per cent.*

Length of drying period	Temperature range (degrees F.)	Per cent germination		Number of samples tested
		Normal grain	Frozen grain	
1 month................	28 to 32	100	100	8
	20 to 24	100	100	8
	12 to 16	100	100	8
	4 to 8	100	97	8
3 months...............	28 to 32	100	100	8
	20 to 24	100	100	8
	12 to 16	100	100	8
	4 to 8	100	100	8

NATURAL RESISTANCE OF GREEN CORN TO COLD

It was thought desirable in connection with this work to determine as nearly as possible not only the degree of cold necessary to weaken or destroy the vitality of the corn kernel but also the length of time necessary for cold to operate before injury results. The latter tests were made as nearly under natural field conditions as possible, so far as the corn itself was concerned,—the ears being undisturbed in the husks, and placed in the freezing apparatus as soon as brought from the field. Five or six ears were frozen at a time. The plan was, to select ears of the four degrees of maturity used in previous tests, and subject them to a given range of temperature for varying periods of time. Again similar sets of ears were subjected for a given time to varying ranges of temperature. As soon as the ears were removed from the freezing chamber, moisture samples were taken and the ear husked and laid away to dry. Later, germination tests were made and notes taken regarding the color of the embryo. The data are compiled in Table 12. The germination tests tend to indicate that light freezing temperatures of short duration are not particularly injurious even to corn of high moisture content, while long exposure, 20-24 hours, to the same temperature may prove fatal. As the temperature is reduced, the duration of exposure necessary to injury becomes shorter. This is indicated in summary Table 13. The data for the 24 hour period in this table are calculated from Tables 5 to 9. While tests at this temperature are not strictly comparable with those of 1915 in that the husks were removed from

TABLE 12—*Effect of exposure to ranges of freezing temperature for different periods of time on the germination of corn differing in moisture content. All ears were protected naturally by the husks (1915)*

Moisture range	Duration of exposure	Minimum temperature	Moisture in grain	Germination	Ice observed in grain	Embryos dark or light
Per cent	*Hours*	*Degrees F.*	*Per cent*	*Per cent*		
75 to 80	4	24	77.4	92	*	Light and dark
	6	32	76.4	100	*	Light
70 to 75	6	32	71.6	100	*	Light and dark
65 to 70	12	28	67.6	83	*	Dark
60 to 65	2	32	62.5	100	*	Light
	4	30	61.5	100	*	Light and dark
	4	28	60.7	100	*	Light
	12	28	64.4	93	*	Light and dark
55 to 60	4	30	59.7	100	*	Light and dark
	4	28	55.9	100	*	Light
	4	14	57.8	75	Ice	Light
	8	23	55.5	100	Ice in some kernels	Light
	8	18	58.8	50	Ice	Light and dark
	8	3	56.7	8	Ice	Dark
	10	14	58.4	19	Ice	Dark
	15	25	56.1	92	Ice in some kernels	Light and dark
50 to 55	2	32	54.5	100	*	Light
	4	24	50.5	100	*	Light and dark
	6	16	51.2	25	Ice	Light and dark
	8	23	52.5	100	*	Dark
	10	23	51.4	91	Ice in some kernels	Light
	10	14	53.2	67	Ice	Light
	10	3	52.7	0	Ice	Dark
45 to 50	2	23	49.5	100	*	Light
	2	10	45.9	85	*	Light and dark
	4	14	45.6	75	Ice	Light and dark
	6	23	48.7	100	*	Light
	8	23	47.8	100	Ice in some kernels	Light and dark
	15	25	48.5	100	Ice in some kernels	Light
	32	25	47.9	75	Ice in some kernels	Light and dark

TABLE 12 *(Continued)—Effect of exposure to ranges of freezing temperature for different periods of time on the germination of corn differing in moisture content. All ears were protected naturally by the husks (1915)*

Moisture range	Duration of exposure	Minimum temperature	Moisture in grain	Germination	Ice observed in grain	Embryos dark or light
Per cent	*Hours*	*Degrees F.*	*Per cent*	*Per cent*		
40 to 45	2	27	43.5	100	*	Light and dark
	2	20	44.4	100	*	Light
	6	23	42.1	100	*	Light and dark
	6	7	42.2	42	Ice	Light and dark
	8	23	45.0	100	Ice in some kernels	Light
	8	18	43.0	100	Ice in some kernels	Light and dark
	8	3	44.2	0	Ice	Dark
	10	14	43.8	67	Ice	Light and dark
	12	21	42.1	100	Ice in some kernels	Light
	12	14	44.6	63	Ice in some kernels	Light and dark
	15	25	44.3	96	Ice in some kernels	Light
35 to 40	2	23	37.9	100	*	Light
	4	5	35.4	45	Ice	Light and dark
	6	23	36.2	100	*	Light
	6	16	38.1	50	Ice in some kernels	Light and dark
	6	7	39.9	50	Ice	Light and dark
	10	23	36.2	100	None	Light and dark
	12	21	39.2	83	None	Light and dark
	12	1	37.3	0	Ice	Light and dark
30 to 35	2	10	33.0	92	*	Light
	4	23	34.1	100	*	Light
	8	3	34.7	47	Ice	Light and dark
	10	23	34.5	100	None	Light
	10	3	34.6	8	Ice	Light and dark
	12	1	32.4	25	Ice	Light and dark
	32	25	33.6	100	None	Light
25 to 30	2	20	29.4	100	*	Light
	2	10	26.6	100	*	Light and dark
	4	5	28.0	92	Ice	Light
	12	21	26.4	100	None	Light
	12	1	27.8	42	Ice	Light and dark
20 to 25	2	20	24.4	100	*	Light
	4	14	24.3	100	None	Light
	6	16	22.2	100	None	Light
15 to 20	8	18	16.4	100	None	Light
	10	3	19.4	92	None	Light and dark
10 to 15	4	5	13.6	100	None	Light

*No observations made.

TABLE 13—*Summary showing effect of length of exposure and degree of cold on the vitality of corn varying in moisture content (1915)*

Moisture in grain	Duration	Minimum temperature 26°F.	Minimum temperature 18°F.	Minimum temperature 10°F.	Minimum temperature 2°F.	Minimum temperature —5°F.
Per cent	*Hours*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*
70 to 80	2	...	...	...	...	..
	4	...	92	...	...	..
	6	100		...	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	83	...	...	...	..
	15	...	...	...	...	..
	24	0	0	...	...	..
60 to 70	2	100	...	...	...	..
	4	100	...	...	...	..
	6	...	...	...	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	88	...	...	...	..
	15	...	...	...	...	..
	24	2	0	0	...	0
50 to 60	2	100	...	...	...	..
	4	100	100	75	...	..
	6	...	...	25	...	..
	8	...	83	...	8	..
	10	...	91	43	0	..
	12	...	...	...	...	..
	15	...	92	...	...	..
	24	32	2	0	0	0
40 to 50	2	100	100	85	...	..
	4	...	...	75	...	..
	6	...	100	...	42	..
	8	...	94	...	0	..
	10	...	...	67	...	..
	12	...	100	63	...	..
	15	...	98	...	...	..
	24	69	12	0	0	0

[1]This table is compiled from Table 12. The germination tests for the 24-hour period are calculated from Tables 5 to 9. Where data is lacking no tests were made.

TABLE 13 *(Continued)—Summary showing effect of length of exposure and degree of cold on the vitality of corn varying in moisture content (1915)*

Moisture in grain	Duration	Minimum temperature 26°F.	Min'mum temperature 18°F.	Minimum temperature 10°F.	Minimum temperature 2°F.	Minimum temperature —5°F.
Per cent	*Hours*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*	*Germination Per cent*
30 to 40	2	...	100	92	...	..
	4	...	100	...	45	..
	6	...	100	50	50	..
	8	...	...	...	47	..
	10	...	100	...	8	..
	12	...	83	...	...	13
	15	...	...	...	...	..
	24	72	40	7	0	0
20 to 30	2	...	100	100	...	..
	4	...	...	100	92	..
	6	...	...	100	...	..
	8	...	...	...	...	..
	10	...	...	...	...	..
	12	...	100	...	...	42
	15	...	...	...	...	..
	24	90	83	64	28	0
10 to 20	2	...	...	...	...	..
	4	...	...	...	100	..
	6	...	...	...	...	..
	8	...	100	...	...	..
	10	...	...	...	92	..
	12	...	...	...	...	..
	15	...	...	...	...	..
	24	...	100	100	99	77

this corn before being exposed to the freezing temperatures, and the minimum temperatures were not exactly the same, yet it was thought that owing to the length of the freezing period both the husked and the unhusked corn would be affected in practically the same way. This is the reason for including the data for the 24-hour period in this table.

VITALITY OF CORN EXPOSED TO FREEZING TEMPERATURES IN THE FIELD

GENERAL SURVEY

As a sort of check on the work done under controlled conditions in the laboratory, a study was made of the vitality of corn exposed to fall and winter freezing in the field during the years 1913-1917. Moisture tests were made at the time the corn was gathered. When the corn was thoroly dry, germination tests were made and the color of the embryo was noted. A record is given of all freezing weather to which the corn was exposed prior to gathering.

Because of the differences in exposure and the repeated freezing and thawing, these data are not strictly comparable with the data obtained from the laboratory tests. However, these data substantiate the principles established under the controlled conditions.

Prior to these more detailed investigations, a general study of the condition of corn had been made in the fall of 1911 and 1912. In the fall of 1911 a severe frost occurred on November 11 and 12. At this time the temperature dropped so low, and corn contained so much moisture, that a very large per cent of the crop in Nebraska was frozen and its power of germination destroyed. The average corn crop contained at that date from 20 to 25 per cent of moisture, and much of it contained more than this amount. The temperature fell as low as 2° F. and remained at that low mark for four hours. (Tables 14 and 15.) Corn which ripened earlier and was drier, however, was not injured. This together with the other field studies and laboratory tests seems to indicate that corn which contains as low as 16 or 17 per cent of moisture is in no danger of losing its vitality from exposure to the ordinary autumn freezes.

The freezing which occurred in 1911 prior to November 13 is indicated in Table 14.

TABLE 14—*Freezing temperatures during autumn 1911. Degrees F.*

Hour of day	Oct. 21	Oct. 23	Oct. 27	Oct. 28	Oct. 29	Oct. 31	Nov. 1	Nov. 2	Nov. 3	Nov. 4	Nov. 7	Nov. 10	Nov. 11	Nov. 12	Nov. 13
A. M.															
12-1	..	..	..	..	..	..	..	16	27	31	..	..	..	4	17
1-2	..	..	..	..	32	..	..	15	27	31	..	32	..	4	19
2-3	..	..	32	32	32	31	..	15	27	31	..	29	..	2	20
3-4	32	..	32	32	32	30	32	14	26	30	..	27	..	2	21
4-5	31	32	32	31	32	29	27	14	26	31	..	23	32	2	21
5-6	31	32	31	30	31	28	26	13	26	32	..	22	30	2	23
6-7	30	..	30	29	..	28	23	12	26	..	32	21	26	3	24
7-8	31	..	31	28	..	27	20	13	26	..	31	21	21	4	25
8-9	..	..	32	32	..	31	21	27	27	..	..	22	17	7	29
9-10	..	..	..	..	..	..	21	22	28	..	..	25	14	9	..
10-11	..	..	..	..	..	..	21	25	29	..	..	28	13	12	..
11-12	..	..	..	..	..	..	21	27	30	..	..	32	12	15	..
P. M.															
12-1	..	..	..	..	..	..	23	28	31	..	..	..	12	17	..
1-2	..	..	..	..	..	..	25	30	31	..	..	..	11	19	..
2-3	..	..	..	..	..	..	24	29	32	..	..	..	11	20	..
3-4	..	..	..	..	..	..	24	29	32	..	..	..	11	20	..
4-5	..	..	..	..	..	..	24	28	..	..	..	..	10	20	..
5-6	..	..	..	..	..	..	22	28	..	..	..	..	10	18	..
6-7	..	..	..	..	..	..	21	27	..	..	..	..	9	18	..
7-8	..	..	..	..	..	..	20	27	..	..	..	..	8	17	..
8-9	..	..	..	..	..	..	19	27	..	..	..	..	7	16	..
9-10	..	..	..	..	..	..	18	26	..	..	..	..	7	15	..
10-11	..	..	..	..	..	..	17	26	31	..	..	..	7	16	..
11-12	..	..	..	..	..	..	16	27	31	..	..	..	6	16	..

TABLE 15—*Duration with mean and minimum temperature of freezing periods during autumn 1911*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 21	5	31.0	30
Oct. 23	2	32.0	32
Oct. 27	7	31.4	30
Oct. 28	7	30.6	28
Oct. 29	5	31.8	31
Oct. 30	7	29.1	27
Nov. 1-3	60	24.2	12
Nov. 3-4	8	31.0	30
Nov. 7	2	31.5	31
Nov. 10	11	25.6	21
Nov. 11-13	53	14.2	2

[1]Compiled from Table 14.

The dates on which the first freezing temperatures recorded by the weather bureau, three miles distant, have occurred during the last seven years are as follows: 1911, October 21; 1912, October 22; 1913, October 20; 1914, October 27; 1915, October 8; 1916, September 29; 1917, October 8.

This shows October 15 to be the average date for the first freezing temperature recorded by the weather bureau, during this period, whereas the average date for the first killing frost was October 12. The freezing temperatures which occurred on the above dates were not low enough, however, to affect the vitality of the corn in any way, unless the corn should have been exceedingly immautre. Even this class of corn is rarely injured by the first freezing temperatures because of their short duration. (See Table 13.)

The approximate moisture content of the average corn crop in eastern Nebraska on October 15, 1911, was 22 per cent; in 1912, it was 20 per cent; in 1913, it was 17 per cent; in 1914, it was 15 per cent; in 1915, it was 35 per cent; in 1916, it was 18 per cent; and in 1917, it was 37 per cent. These figures are based on the moisture content of corn harvested from the general field plats of the Experiment Station. They represent, no doubt, very nearly the average maturity of corn in eastern Nebraska at the time when freezing temperatures are likely to occur. It will be seen that usually corn is too mature to be injured in vitality by the first freezing weather. Even in 1915 when the moisture content was large the first freezing did little or no damage to the life of the seed. (See Table 22.) Farther north and west in the State, however, the season is shorter and freezing comes earlier. The corn in these sections, therefore, should be correspondingly earlier in order to insure normal vitality in the seed. Heavier freezing during the late fall and winter is more likely to do serious damage to the germination of corn not fully matured.

FIELD SELECTION IN 1913

In the fall of 1913, corn samples of various degrees of dryness were selected from the field on October 30, after 9 days of considerable freezing weather, during which time 98 hours of freezing temperature prevailed, with a minimum of 15° F. The notes on viability and color of germ are given in Table 16. The freezing temperatures which occurred during the fall and to which the corn had been exposed are indicated in Table 17. Table 18 summarizes these temperatures, giving the duration and the mean and minimum temperature of each freezing period.

TABLE 16—*Germinative ability of corn which varied in degree of maturity and which was exposed in the field to the freezing temperatures of autumn. The degree of maturity is indicated by the moisture content of the grain. Corn harvested October 30, 1913.*[1]

Moisture range	Moisture in grain	Germination	Embryos dark or light
Per cent	*Per cent*	*Per cent*	
35 to 40	39.7	0	Dark
	39.7	0	Dark
	39.4	0	Dark
	37.0	0	Dark
	36.9	20	Dark
	35.7	0	Dark
Average	38.1	3	
30 to 35	34.3	40	Light
	34.1	0	Dark
	33.5	20	Dark
	32.9	60	Light
	32.3	0	Dark
Average	33.4	24	
25 to 30	30.0	20	Medium dark
	29.8	0	Dark
	27.7	40	Light
	27.6	100	Light
	27.1	60	Dark and light
	26.7	80	Light
	26.4	0	Dark
Average	27.9	43	
20 to 25	24.4	100	Light
	23.9	80	Light
	23.2	80	Light
	22.7	100	Light
	22.3	100	Light
	21.2	100	Light
Average	23.0	93	
15 to 20	20.0	100	Light
	19.4	100	Light
	15.3	100	Light
	15.3	100	Light
Average	17.5	100	
10 to 15	14.2	100	Light
	14.1	100	Light
Average	14.2	100	

[1]See Tables 17 and 18 for freezing temperatures prior to October 30.

TABLE 17—*Freezing temperatures during autumn, 1913. Degrees F.*

Hours of day	Oct. 19	Oct. 20	Oct. 21	Oct. 23	Oct. 26	Oct. 27	Oct. 28	Oct. 29	Oct. 30	Oct. 31	Nov. 1
A. M.											
12-1	..	26	28	..	..	28	..	21	23	25	..
1-2	..	25	26	32	..	26	..	21	22	24	32
2-3	..	24	25	32	..	25	..	21	21	23	32
3-4	..	23	24	..	..	24	..	21	20	23	32
4-5	..	23	23	..	..	23	..	19	19	22	32
5-6	..	25	23	..	..	22	..	18	19	22	32
6-7	..	27	22	..	..	24	31	15	18	22	32
7-8	..	29	24	..	32	21	30	15	18	23	..
8-9	..	32	26	..	32	30	28	17	21	25	..
9-10....	..	..	28	..	..	..	27	20	24	32	..
10-11....	..	..	31	..	..	..	26	23	28	..	..
11-12....	..	..	..	..	..	..	26	26	..	..	..
P. M.											
12-1	..	..	..	..	..	..	26	28	..	..	..
1-2	..	..	..	..	..	..	27	31	..	..	..
2-3	..	..	..	..	..	..	28	..	..	..	..
3-4	..	..	..	..	..	..	28	..	..	..	..
4-5	..	..	..	..	..	..	26	32	..	..	..
5-6	..	..	..	..	..	..	25	30	..	..	..
6-7	..	..	..	..	..	..	24	28	..	..	..
7-8	30	..	..	..	..	..	23	27	..	..	..
8-9	28	..	..	..	..	..	23	26	31	..	..
9-10....	27	..	..	..	..	..	23	26	29	..	..
10-11....	29	..	..	..	32	..	23	25	27	..	..
11-12....	28	29	..	..	29	..	22	23	25	..	..

TABLE 18—*Duration with mean and minimum temperatures of freezing periods during autumn of 1913* [1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 19-20......................	14	26.9	23
Oct. 20-21......................	12	25.8	22
Oct. 23.........................	2	32.0	32
Oct. 26.........................	2	32.0	32
Oct. 26-27......................	11	25.8	21
Oct. 28-29......................	32	23.8	15
Oct. 29-30......................	19	23.4	18
Oct. 30-31......................	14	25.2	22
Nov. 1..........................	6	32.0	32

[1]Compiled from Table 17.

The corn was grouped according to its moisture content, with a range of 5 per cent for each group. Corn ranging in moisture content from 10 to 15 per cent, and 15 to 20 per cent gave 100 per cent germination; 20 to 25 per cent moisture germinated 93 per cent; 25 to 30 per cent moisture germinated 43 per cent; 30 to 35 per cent moisture germinated 24 per cent; and 35 to 40 per cent moisture germinated 3 per cent.

These results conform very closely to those from the laboratory tests at a temperature range of 16° to 12° F., as may be seen by comparing with Table 7. In the laboratory, when subjected to a temperature of 16° to 12° F., corn containing 15 to 20, 20 to 25, 25 to 30, 30 to 35, and 35 to 40 per cent of water germinated respectively 100, 88, 34, 12, and 0 per cent, while the same grades of corn exposed in the field to a minimum temperature of 15° F. germinated respectively 100, 93, 43, 24, and 3 per cent.

FIELD SELECTION IN 1914

The results for corn selected from the field on November 22, 1914, after intermittent subjection to 111 hours freezing temperature with a minimum of 4° F. are given in Table 19. The freezing temperatures are given in detail in Table 20 and are summarized in Table 21, which gives the duration and the mean, and minimum temperatures for each freezing period. The respective mean germinations were 100, 67.5, 60, 55, and 30 per cent according to whether the moisture content of the grain ranged from 10 to 15, 15 to 20, 20 to 25, 25 to 30, or 30 to 35 per cent.

FIELD SELECTION IN 1915

A study was made in the fall of 1915 of the effect of early freezing temperatures on the vitality of corn when left in the field and exposed to the natural freezing weather of October and November. This year the corn was very immature at the time of the first killing frost and continued to retain a large per cent of water thruout the fall. Since there was also considerable variation in the maturity of individual ears, the opportunity was exceptionally good for studies of this kind. The freezing temperatures which occurred during the fall are recorded in Table 24, and put in summary form in Table 25. It will be noted from these that the first freezing occurred on October 8, and again on October 9. The first was very light and of short duration, while the second was more severe and slightly longer.

TABLE 19—*Germinative ability of corn which varied in degree of maturity and which was exposed in the field to the freezing temperatures of autumn. The degree of maturity is indicated by the moisture content of the grain. Corn harvested November 22, 1914*[1]

Moisture range	Moisture in grain	Germination	Embryos dark or light
Per cent	*Per cent*	*Per cent*	
30 to 35	34.2	0	Dark
	31.3	60	Light
Average	32.8	30	
25 to 30	29.4	60	Dark
	28.7	80	Dark and light
	26.5	20	Dark
	26.3	60	Light
Average	27.7	55	
20 to 25	24.2	20	Dark
	24.0	20	Dark and light
	23.6	60	Light
	22.5	100	Light
	21.4	80	Dark
	21.2	60	Dark
	21.1	100	Light
	20.5	60	Dark and light
	20.2	40	Dark and light
Average	22.1	60	
15 to 20	19.9	40	Light
	19.9	60	Light
	19.6	20	Dark and light
	19.2	100	Light
	18.8	40	Dark and light
	17.8	100	Light
	17.6	100	Light
	16.8	80	Light
Average	18.7	67.5	
10 to 15	13.4	100	Light

[1]See Tables 20 and 21 for freezing temperatures prior to November 22.

TABLE 20—*Freezing temperatures during autumn, 1914. Degrees F.*

Hours of day	Oct. 26	Oct. 27	Nov. 8	Nov. 13	Nov. 15	Nov. 16	Nov. 17	Nov. 18	Nov. 19	Nov. 20	Nov. 22
A. M.											
12-1	..	28	..	..	..	22	25	..	12	19	..
1-2	..	27	31	..	..	23	25	..	10	19	..
2-3	..	27	30	..	..	22	25	..	8	20	..
3-4	..	26	29	..	..	21	26	..	7	21	..
4-5	..	25	28	..	..	19	27	32	6	22	32
5-6	..	24	27	..	..	18	28	31	5	22	30
6-7	..	25	26	..	..	18	29	..	5	22	30
7-8	..	26	26	32	31	19	28	..	4	23	29
8-9	..	31	30	..	29	21	30	..	6	26	28
9-10....	..	..	..	..	30	24	..	..	8	..	..
10-11....	..	..	..	..	31	25	..	..	11	..	..
11-12....	..	..	..	..	..	27	..	..	14	..	..
P. M.											
12-1	..	..	..	..	..	29	..	..	18	..	..
1-2	..	..	..	..	..	31	..	..	19	..	..
2-3	..	..	..	..	..	32	..	..	21	..	..
3-4	..	..	..	..	..	32	..	..	22	..	..
4-5	..	..	..	..	..	31	..	..	21	..	..
5-6	..	..	..	..	31	28	..	..	20	..	..
6-7	..	..	..	..	30	27	..	..	20	..	..
7-8	..	..	..	..	27	25	..	32	20	..	..
8-9	32	..	..	..	25	25	..	27	19	..	..
9-10....	30	..	..	..	23	24	..	23	19	..	..
10-11....	30	..	..	..	22	25	..	19	18	..	..
11-12....	28	..	..	..	21	24	..	15	18	..	..

TABLE 21—*Duration with mean and minimum temperatures of freezing periods during autumn of 1914*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 26-27	13	27.6	24
Nov. 8	8	28.4	26
Nov. 13	1	32.0	32
Nov. 15	4	30.2	29
Nov. 15, 16, 17	40	25.3	18
Nov. 18	2	31.5	31
Nov. 18, 19, 20	38	16.9	4
Nov. 22	5	29.8	28

[1]Compiled from Table 20.

EFFECT OF EARLY FREEZING ON VARIETIES, 1915

On October 10, corn was gathered from twenty-seven different varieties and hybrids for moisture and germination tests. These varieties and hybrids represented many different stages of maturity at the time the frost came. Some were late varieties and were still very immature, while others were early and were comparatively dry. Intermediate stages were also represented. The moisture content of the grain and also of the cob at the time of harvest, together with the germination for each variety, is shown in Table 22. It will be noted from this table that the moisture content of the grain was still rather large for most varieties. The germination tests, however, are so nearly perfect for all, that it seems hardly possible to trace any injury back to the effect of the frost.

TABLE 22—*The germination of corn varying in degree of maturity and gathered on October 10, after the first killing frost in 1915. The degree of maturity is indicated by the per cent of moisture in the cob and in the grain*[1]

Variety name	Tasseling date	Per cent moisture		Per cent germination
		Cob	Grain	
Hogue's Yellow Dent	8–16	57.0	38.0	99
Boone Co. White	8–21	60.3	44.7	97
Boone Co. White x Hogue's	8–20	64.9	47.9	99
Nebraska White Prize	8–20	61.2	45.2	100
Nebraska White Prize x Hogue's	8–18	63.3	43.2	99
Bloody Butcher	8–19	55.0	39.9	99
Bloody Butcher x Hogue's	8–18	57.7	43.2	94
Calico	8–17	59.2	40.4	100
Calico x Hogue's	8–17	55.3	40.4	100
Reid's Yellow Dent	8–16	60.8	37.8	97
Reid's Yellow Dent x Hogue's	8–16	59.1	35.2	99
Iowa Silver Mine	8–15	51.1	33.7	99
Iowa Silver Mine x Hogue's	8–14	57.9	40.6	99
St. Charles White	8–13	53.8	31.6	100
St. Charles White x Hogue's	8–15	58.0	32.1	100
Pride of the North	8–13	41.1	23.8	100
Pride of the North x Hogue's	8–15	51.5	32.9	99
University No. 3	8–13	57.3	35.4	97
University No. 3 x Hogue's	8–14	56.6	36.5	99
White Cap	8–12	50.3	29.0	100
White Cap x Hogue's	8–14	52.5	33.6	97
Iowa Gold Mine	8–10	51.6	31.6	99
Iowa Gold Mine x Hogue's	8–12	55.5	35.4	97
Leaming	8– 9	57.1	33.8	99
Leaming x Hogue's	8–13	55.1	39.0	100
Minnesota No. 13	8– 4	40.9	18.3	100
Minnesota No. 13 x Hogue's	8– 8	47.4	26.6	100

[1]See Tables 24 and 25 for freezing temperatures prior to October 10.

EFFECTS OF MORE SEVERE FREEZING, 1915

On the morning of November 9, while the frost was still on, a number of ears were examined in the field for ice formation in the kernels. Moisture samples were taken from these ears and germination tests were made later. After rather severe freezing on November 14, and again on the 15th, observations were made, the same being taken as in the previous case. The data are compiled in Table 23. One interesting thing shown in this table is that ice formation in the kernel is not necessarily fatal to the vitality of the grain, also that the freezing of November 9 with a minimum of 30° F. and lasting five hours was not of sufficient duration to affect germination. From the data of November 15 it is interesting to note that even those ears on which the kernels were a solid frozen mass gave a fair per cent of germination. In these cases, however, the viability plainly was reduced.

TABLE 23—*Germinative ability of corn which was exposed in the field to the freezing temperatures of autumn, 1915*[1]

Extent of freezing in kernels	Moisture content	Germination
CORN GATHERED NOVEMBER 9	*Per cent*	*Per cent*
SECOND LIGHT FREEZE		
Not frozen, no ice found in kernels	36.0	100
Not frozen, no ice found in kernels	32.2	100
Not frozen, no ice found in kernels	31.3	100
Ice found in the base of some of the kernels	39.1	100
Ice found in the base of some of the kernels	30.7	100
Ice found in the base of some of the kernels	41.9	100
Ice found in the base of some of the kernels	41.8	100
Ice found in the base of some of the kernels	47.8	100
CORN GATHERED NOVEMBER 15		
FIRST SEVERE FREEZE		
Whole kernel frozen solid	53.3	67
Germ frozen solid, rest of kernel not frozen	43.4	67
Ice in base of kernel, germ and endosperm not frozen	26.3	75
Not frozen, no ice found in kernel	16.9	100

[1]See Tables 24 and 25 for freezing temperatures prior to November 15.

TABLE 24—*Freezing temperatures during autumn of 1915. Degrees F.*

Hours of day	Oct. 8	Oct. 9	Nov. 9	Nov. 13	Nov. 14	Nov. 15	Nov. 16
A. M.							
12-1	..	32	..	..	26	24	..
1-2	..	30	32	..	25	24	..
2-3	..	30	31	..	24	24	..
3-4	..	..	31	..	23	23	..
4-5	..	..	30	..	22	23	..
5-6	..	..	30	..	22	23	31
6-7	32	..	..	..	22	24	29
7-8	..	..	..	..	21	27	27
8-9	..	..	..	..	26	30	28
9-10	..	..	..	..	30	..	..
10-11	..	..	..	..	..	..	..
11-12	..	..	..	..	..	..	..
P. M.							
12-1	..	..	..	..	..	..	..
1-2	..	..	..	..	..	..	..
2-3	..	..	..	..	..	..	..
3-4	..	..	..	..	..	..	..
4-5	..	..	..	31	..	..	..
5-6	..	..	..	30	..	..	..
6-7	..	..	..	30	31	..	..
7-8	..	..	..	29	30	..	..
8-9	..	..	..	28	28	..	..
9-10	..	..	..	28	27	..	..
10-11	..	..	..	28	26	..	..
11-12	..	..	..	28	25	..	..

TABLE 25—*Duration with mean and minimum temperatures of freezing periods during autumn, 1915*[1]

Date	Hours in period	Mean temperature degrees F.	Minimum temperature degrees F.
Oct. 8	1	32.0	32
Oct. 9	3	30.7	30
Nov. 9	5	30.8	30
Nov. 13-14	18	26.3	21
Nov. 14-15	15	25.9	23
Nov. 16	4	28.8	27

[1]Compiled from Table 24.

VARIATION WITHIN A SINGLE EAR

It was observed that there was a great variation in the maturity and moisture content of kernels on the same ear.

In order to determine definitely the actual difference which may be found, moisture tests were made. For this purpose two ears were selected showing great variation in maturity of different kernels. The kernels from each ear were divided into groups according to maturity. The kernels from one ear were grouped as dry, and as damp. Only the extreme types were taken. The dry group represented the driest kernels on the ear, while the damp group represented the most immature kernels. Sprouted kernels were found on the other ear, and these were placed in a group by themselves. Moisture tests were then made for each group from each ear. The results are shown in Table 26. The table shows an average difference of 15.8 per cent between the damp and dry kernels. The sprouted kernels averaged 60.7 per cent moisture. The difference here indicated is sufficient to cause a great difference in susceptibility to cold, as indicated in previous tables, and no doubt explains in many cases why some kernels of an ear are killed by freezing while others are uninjured.

TABLE 26—*Variation in moisture content of kernels from the same ear of corn at the time of harvest. November 10, 1915*

Ear	Description of Kernels	Moisture content
		Per cent
1	Least mature	65.4
	Most mature	49.2
2	Least mature	63.5
	Most mature	48.2
	Sprouted	60.7

FIELD SELECTIONS IN 1917

Climatic conditions combined in such manner in 1917 that no season in this generation has been quite so unfavorable to the maturing and drying of the corn crop. The early growth was retarded by a cold, wet spring. Later it was again retarded by deficient moisture in July. Following that came an unusually cool August and September, which prolonged growth and delayed ripening. The first killing frost in the early morning of October 8, with a duration of nine hours and a minimum temperature of 24° F., (Table 30) was an unusually severe first frost. This was followed by three weeks of cold and freezing weather which not only retarded the drying of corn but continued to reduce its vitality.

EFFECT OF FIRST KILLING FROST ON VARIETIES, 1917

The test with corn varieties and hybrids reported in Table 22 for 1915, was repeated in 1917. Types varying widely as to earliness and related moisture content were represented. An unusually large amount of moisture was present at the time of the first killing frost on October 8. Ten ears of each variety and hybrid were gathered the following day and tested for moisture and germination. The results are given in Table 27. The varieties and their hybrids represented many different stages of maturity at the time they were gathered for testing. The grain varied from 16 to 47 per cent moisture content, according to variety. The germination tests show very little injury from this first frost, even for the late maturing varieties.

TABLE 27—*Germination of corn varying in degree of maturity and gathered after the first killing frost on October 8, 1915. The degree of maturity is indicated by the per cent of moisture in the grain.*

Variety name	Tasseling date	Per cent moisture	Per cent germination
Hogue's Yellow Dent	8– 7	39	94
Boone Co. White	8–12	46	97
Boone Co. White x Hogue's	8–11	50	88
Nebraska White Prize	8–10	44	96
Nebraska White Prize x Hogue's	8– 8	42	99
Bloody Butcher	8–11	46	93
Bloody Butcher x Hogue's	8–10	47	94
Calico	8–10	34	94
Calico x Hogue's	8–10	41	95
Reid's Yellow Dent	8– 6	38	100
Reid's Yellow Dent x Hogue's	8– 7	44	99
Iowa Silver Mine	8– 7	26	100
Iowa Silver Mine x Hogue's	8– 7	44	92
St. Charles White	8– 5	37	94
St. Charles White x Hogue's	8– 6	38	96
Pride of the North	8– 2	29	95
Pride of the North x Hogue's	8– 5	37	97
University No. 3	8– 8	37	95
University No. 3 x Hogue's	8– 8	40	95
White Cap	8– 5	38	96
White Cap x Hogue's	8– 6	34	96
Iowa Gold Mine	8– 9	32	95
Iowa Gold Mine x Hogue's	8– 8	41	88
Leaming	8– 8	37	94
Leaming x Hogues	8– 7	44	94
Minnesota No. 13	8– 2	17	99
Minnesota No. 13 x Hogue's	8– 4	27	92

[1]For freezing temperatures see Table 30.

DEGREES OF MATURITY SELECTED FROM FIELD AT DIFFERENT DATES IN FALL AND WINTER OF 1917

Five 10-ear samples of corn differing in maturity and moisture content were selected from a field of Hogue's Yellow Dent corn on October 8, 1917, following the first, but severe, freezing spell of the season. As nearly corresponding samples as possible were selected at four succeeding dates, namely on November 19, December 11, December 29, and January 15, for the purpose of observing the effects of additional degrees of freezing under natural field conditions. The field was neither the ripest nor the greenest at the Station, but was of medium maturity, and represented about an average condition for eastern Nebraska that season. The five selected samples of this seed ranged from mature seed down to the late dough stage of maturity.

Two additional samples were selected from other fields at each of the above dates and tested together with the above five samples. One was mature seed selected from a field of Hogue's Yellow Dent corn which had been cut and shocked late in September. The other was very immature seed selected in the milk stage from a field of late planting.

A description of the seven samples together with their moisture content and germination are given in Tables 28 and 29.

TABLE 28—*Germinative ability of Hogue's Yellow Dent corn which was exposed in the field to various amounts of freezing during the fall and winter of 1917*

Condition of corn at time of first killing frost, October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Im-perfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Corn gathered October 8—First killing frost with minimum temperature 24°F.							
Shocked corn:							
1. Fairly well matured, ears solid	30[1]	50	30	98	0	98	100
Corn standing in field:							
2. Fairly well matured, ears solid	7	56	35	98	0	98	100
3. Somewhat rubbery, ears twist	15	58	39	94	3	97	100
4. Very rubbery, grain medium soft	22	61	43	92	5	97	100
5. Grain very soft	25	61	47	92	1	93	100
6. Late dough stage	30	63	50	82	10	92	100
7. Milk stage	..[1]	63	63	44	11	55	100
Corn gathered November 19—Prolonged freezing with minimum of 17°F.							
Shocked corn:							
1. Fairly well matured, ears solid	30	26	17	85	13	98	100
Corn standing in field:							
2. Fairly well matured, ears solid	7	23	17	83	8	91	90
3. Somewhat rubbery, ears twist	15	39	21	56	15	71	52
4. Very rubbery, grain medium soft	22	45	26	34	7	41	21
5. Grain very soft	25	48	27	14	3	17	8
6. Late dough stage	30	50	34	10	4	14	10
7. Milk stage	..	52	36	1	1	2	0

[1]The samples for lots 1 and 7 were taken from a different field than the other samples.

TABLE 28 *(Continued)—Germinative ability of Hogue's Yellow Dent corn which was exposed in the field to various amounts of freezing during the fall and winter of 1917*

Condition of corn at time of first killing frost, October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Im-perfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Corn gathered December 11—Prolonged freezing with minimum of —16°F.							
Shocked corn:							
1. Fairly well matured, ears solid	30	16	15	93	5	98	100
Corn standing in field:							
2. Fairly well matured, ears solid	7	17	16	87	4	91	88
3. Somewhat rubbery, ears twist	15	25	18	79	6	85	87
4. Very rubbery, grain medium soft	22	38	23	20	5	25	6
5. Grain very soft	25	44	26	17	2	19	4
6. Late dough stage	30	47	28	10	1	11	0
7. Milk stage	..	47	33	0	0	0	0
Corn gathered December 29—Prolonged freezing with minimum of —18°F.							
Shocked corn:							
1. Fairly well matured, ears solid	30	18	16	87	11	98	100
Corn standing in field:							
2. Fairly well matured, ears solid	7	17	15	93	5	98	88
3. Somewhat rubbery, ears twist	15	18	16	59	15	74	62
4. Very rubbery, grain medium soft	22	31	19	14	11	25	0
5. Grain very soft	25	33	21	5	7	12	0
6. Late dough stage	30	44	28	0	0	0	0
7. Milk stage	..	45	29	0	0	0	0

TABLE 28 *(Continued)—Germinative ability of Hogue's Yellow Dent corn which was exposed in the field to various amounts of freezing during the fall and winter of 1917*

Condition of corn at time of first killing frost, October 8	Proportion of total corn in field	Moisture Content		Germination			Estimated germination based on color of germ
		Cob	Grain	Perfect	Im-perfect	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Corn gathered January 17—Prolonged freezing with minimum temperature of —21°F.							
Shocked corn:							
1. Fairly well matured, ears solid	30	15	14	86	10	96	88
Corn standing in field:							
2. Fairly well matured, ears solid	7	15	14	88	6	94	90
3. Somewhat rubbery, ears twist	15	17	17	61	12	73	70
4. Very rubbery, grain medium soft	22	26	19	20	6	26	10
5. Grain very soft	25	36	22	6	1	7	0
6. Late dough stage	30	43	27	0	0	0	0
7. Milk stage	..	42	28	0	0	0	0

TABLE 29—*Summary showing moisture content and germination of corn harvested at various dates during fall and winter of 1917*[1]

Condition of corn at time of first killing frost, October 8	Moisture in grain of corn gathered on					Per cent perfect germination of corn gathered on				
	Oct. 8	Nov. 19	Dec. 11	Dec. 29	Jan. 17	Oct. 8	Nov. 19	Dec. 11	Dec. 29	Jan. 17
Shocked corn:										
1. Fairly well matured, ears solid	30	17	15	16	14	98	85	93	87	86
Corn standing in field:										
2. Fairly well matured, ears solid	35	17	16	15	14	98	83	87	93	88
3. Somewhat rubbery, ears twist	39	21	18	16	17	94	56	79	59	61
4. Very rubbery, grain medium soft	43	26	23	19	19	92	34	20	14	20
5. Grain very soft	47	27	26	21	22	92	14	17	5	6
6. Late dough stage	50	34	28	28	27	82	10	10	0	0
7. Milk stage	63	36	33	29	28	44	1	0	0	0
Minimum temp. (degrees F.)	..	..	..	..	..	24	17	—16	—18	—21

[1]Compiled from Table 28. For a record of all freezing temperatures prior to each selection from the field, see Table 30.

The freezing temperatures prevailing up to the time of the last selection—January 17, 1918—are indicated in Table 30.

TABLE 30—*Duration, mean temperature, and minimum temperature of freezing periods during autumn and early winter (1917-1918)*

Date	Hours in period	Mean temperature (degrees F.)	Minimum temperature (degrees F.)
Oct. 8	9	27.7	24
Oct. 10	1	32.0	32
Oct. 11-12	11	26.8	23
Oct. 12-13	8	27.9	25
Oct. 18-19	13	23.8	18
Oct. 20-21	5	31.2	31
Oct. 22-23	13	28.8	23
Oct. 24	2	32.0	32
Oct. 26	5	31.0	30
Oct. 27	6	31.0	30
Oct. 28-30	45	25.2	17
Oct. 30-31	12	26.7	24
Oct. 31-Nov. 1	12	27.8	26
Nov. 1-2	10	30.2	29
Nov. 4	5	30.2	29
Nov. 18-19	14	26.1	21
Nov. 23	10	28.1	24
Nov. 23-24	15	25.4	19
Nov. 24-25	17	30.2	28
Nov. 26	2	32.0	32
Nov. 26-27	5	30.6	30
Nov. 27-28	14	23.4	18
Nov. 29	3	32.0	32
Nov. 30	9	28.7	26
Nov. 30-Dec. 1	10	28.1	26
Dec. 1-2	10	28.6	27
Dec. 3	12	25.9	22
Dec. 3-4	14	20.1	22
Dec. 4-16	290	5.6	—16
Dec. 17	3	31.7	31
Dec. 18	5	30.6	30
Dec. 20-21	14	26.4	25
Dec. 21-22	14	27.0	20
Dec. 24-26	61	17.6	12
Dec. 26-Jan. 1	136	11.3	—18
Jan. 2-3	33	20.7	15
Jan. 3-4	16	29.1	25
Jan. 5-17	290	7.0	—23

At 9 o'clock A. M., on October 8, following the heavy frost earlier in the morning, a thermometer inserted into the center of the cob of corn ears hanging naturally in the field recorded a temperature of 31.5° F. Thus the freezing temperature of this first freeze penetrated thru the husks to the center of the ear. The grain on the more immature ears was considerably frozen. The selection of the various samples, as described in Table 28, was based entirely upon the external appearance and feel of the ear. At each successive selection the corn was noticeably drier. However, each sample in the later selections was chosen as nearly as possible to duplicate the corn in the corresponding sample in the first selection. No attention was given to the appearance of the germ in selecting each sample. However, the germs were later examined for color, and the probable germination was estimated, based upon the color of the germ. The data in Table 28 show that a fairly reliable estimate of viability may be made by an examination of the germ.

The data in Table 29 indicates that most of the freezing injury to seed corn in the field in 1917 occurred between October 8 and November 19, and that little injury occurred following this date. Altho much more severe freezing followed, the corn had dried out sufficiently to withstand it. In general, corn in the field which was sound on November 19, 1917, was also sound on January 15, 1918.

The vitality of grain containing more than 17 per cent of moisture on November 19 was so reduced by the temperatures which prevailed up to that date as to make it unreliable for seed purposes. On the other hand, the driest grade standing in the field, and that from the shocked corn, was not injured seriously, giving germination tests of 86, and 88 per cent perfect germination respectively, tho exposed to all the low temperatures prior to January 17. On this date, the field from which the various selections reported in Tables 28 and 29 were made tested 31 per cent germination, field-run.

CONDITION OF CORN IN CRIBS ON JANUARY 26, 1918

The condition of corn in three Lancaster County corncribs was investigated on January 26, 1918. These cribs contained Reid's Yellow Dent, Chase's White Dent and St. Charles' White Dent corn. The crib-run tests of these cribs were 45, 39, and 26 per cent germination respectively. The corresponding tests of seed selected because of the sound outward appearance of the ears were 86, 89, and 90 per cent germination. It was estimated that to select 1 bushel of these grades of corn from each of these cribs required 80, 100, and 140 minutes respectively for one man. All these tests could doubtless have been improved by further testing and elimination of the inferior ears. Seven, six, and three per cent of the corn in the respective cribs were selected for the above grades.

THE DANGER LINE OF FREEZING INJURY

An approximate safety zone free from freezing injury may be established for seed corn differing in moisture content. The combinations of low temperature and freezing duration which seed corn will withstand as indicated in Fig. 13, are constructed from the various tests reported in this bulletin and should be regarded as approximate rather than absolute. They set forth the probable duration of a given low temperature which corn of given moisture content will withstand without injury. A slight lowering of the temperature or a longer duration of the exposure may initiate a reduction in the per cent germination but will not prove entirely fatal. Greater fatality will result as the adverse factors are extended.

It will be noted that in general an extension of the time of exposure is comparatively as dangerous as is the lowering of the temperature, until the moisture content in the grain is reduced to nearly 20 per cent where it manifests a decidedly greater resistance to the duration of exposure. A still more marked proportional resistance to the duration of exposure is shown by corn containing as low as 17 per cent moisture. When air-dry, containing 14 per cent or less of moisture, corn will endure any natural low winter temperature for any length of time.

OCCURRENCE OF AUTUMN FROSTS IN NEBRASKA

The dates for the first autumn frosts occur with great irregularity in Nebraska. As extremes for Lincoln, Nebr., during the last 21 years, the first killing frost occurred in 1902 on September 12, and in 1914 on October 27. As seen in Table 31 the dates of the first killing frost and the first dates with a recorded freezing temperature of 32° F. or lower do not always coincide. This is due to the fact that the Weather Bureau temperatures are obtained at a considerable distance above the ground, where the temperature does not always drop quite so low as it does nearer the surface. The average date of the first killing frost at Lincoln during the past 21 years has been October 12.

Table 31 gives the duration of the first freezing temperature together with the mean and minimum temperatures of the period, during the last 21 years at Lincoln.

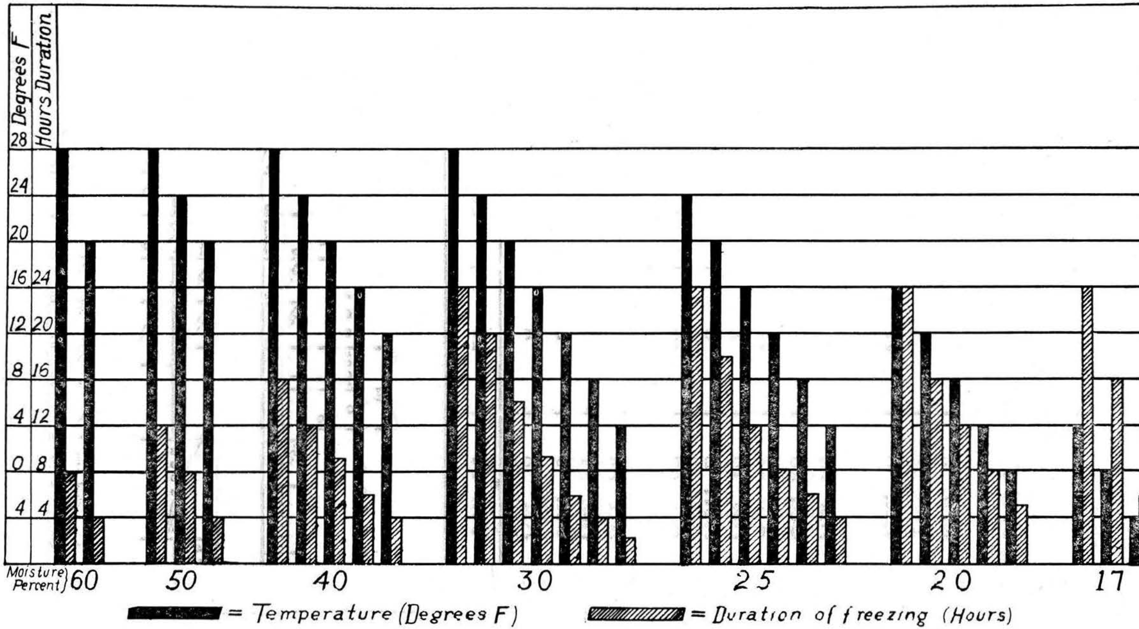


Fig. 13—The points of danger to seed corn of various moisture contents from freezing injury at given temperatures and stated hours of continuous exposure. A material adverse extension of freezing temperature, duration of freezing, or moisture content is likely to reduce the per cent germination. Air-dry corn containing less than 14 per cent moisture will withstand any natural low winter temperature for any length of time.

TABLE 31—*Dates of the first killing frost and of the first freezing temperatures at Lincoln, Nebr., during 21 years, 1897 to 1917*

Year	Date of first killing frost	First date with temperature of 32°F. or below	Duration of freezing temperature	Mean temperature during period	Minimum temperature during period
			(Hours)	*(Degrees F.)*	*(Degrees F.)*
1897	Oct. 29	Nov. 2	10	30.0	29
1898	Oct. 6	Oct. 6	3	31.7	31
1899	Sept. 29	Sept. 29	7	29.3	27
1900	Oct. 17	Nov. 8	14	26.3	21
1901	Sept. 18	Sept. 18	3	31.7	31
1902	Sept. 12	Oct. 28	6	30.5	29
1903	Oct. 27	Oct. 27	3	31.7	31
1904	Oct. 25	Oct. 25	3	31.7	31
1905	Oct. 20	Oct. 20	7	31.0	30
1906	Oct. 10	Oct. 10	10	29.5	26
1907	Oct. 12	Oct. 12	4	31.0	30
1908	Oct. 11	Nov. 2	5	31.0	30
1909	Oct. 12	Oct. 12	16	28.0	21
1910	Oct. 22	Oct. 27	12	29.0	26
1911	Oct. 20	Nov. 1, 2 and 3	58	23.6	12
1912	Sept. 30	Oct. 22	6	31.3	30
1913	Oct. 20	Oct. 20	14	27.0	23
1914	Oct. 27	Oct. 27	13	28.0	24
1915	Oct. 9	Oct. 9	3	31.3	30
1916	Sept. 29	Sept. 29	5	31.0	30
1917	Oct. 8	Oct. 8	9	27.7	24
Av'ge	Oct. 12	Oct. 18	10	29.6	27

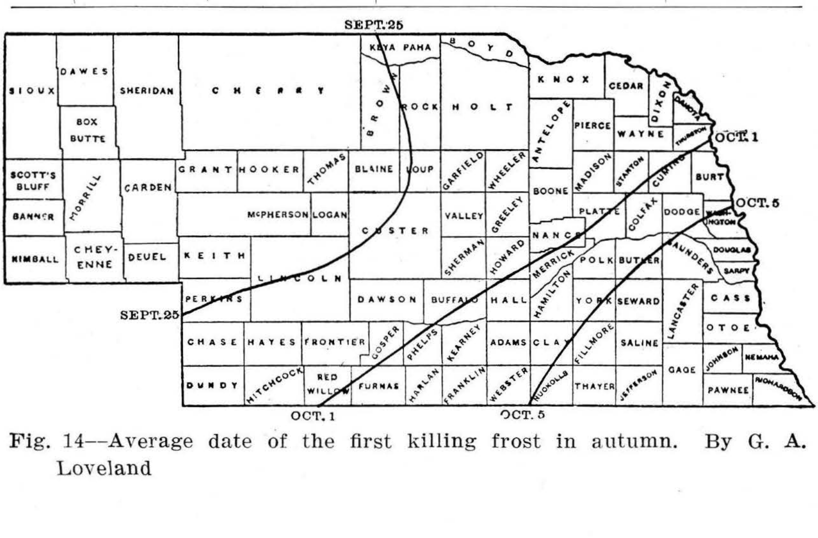


Fig. 14—Average date of the first killing frost in autumn. By G. A. Loveland

This variation in time of freezing weather together with a great seasonal variation in time of corn maturity has a marked bearing in different years upon the condition of corn for seed when left standing in the field.

The average dates of the first killing frost in the field in the fall for various parts of Nebraska are given in Figure 14.

FREEZING INJURY INEVITABLE IN OCCASIONAL YEARS

Experience has taught that the best adapted, highest producing corn for any locality in Nebraska, or in the greater part of the Corn Belt, does not mature and dry sufficiently in all seasons to escape freezing injury when left exposed to low temperatures either in the field or in the crib. It would not be practicable in most of the Corn Belt to grow corn sufficiently early to escape damage from freezing every year, because such corn would be too small and early to give best results. The best adapted and most productive types appear to be those which utilize practically the entire growing season of the average year. In the majority of years, such types should ripen fully before the first killing frost, altho in occasional years both the yield and the quality may be reduced by autumn frosts.

Seasonal variation in the time of maturity of a given corn in a given locality may be illustrated by the relative maturity of Hogue's Yellow Dent corn at the Experiment Station in 1914 and 1917. This is a standard well-adapted type for conditions prevailing at the Experiment Station. In 1914 the grain of this corn contained only 14 per cent moisture on October 1, while it contained 38 per cent on October 1, 1917. It was well matured on September 6, 1914, whereas it was not so mature a month later in 1917. In this vicinity the normal date of ripening for this variety is September 20, while the mean date of the first killing frost is October 11. According to this, corn which is unsurpassed in average production at the Experiment Station ripens, as an average, about 3 weeks before the mean date of the first killing frost.

This seasonal variation makes possible in many years the growing of late maturing types of corn in localities where they normally are not adapted. But the character of the season and the date of the first killing frost cannot be foretold at planting time. Therefore, unadapted, late maturing types which do not reach their full development before the average date of the first killing frost should not be grown. They require for their full development the exceptional seasons in which the first killing frost comes very late. In too great a proportion of the seasons they fail to mature, and too frequently produce an inferior quality of corn together with a low yield of grain per acre.

SELECTION FOR EARLINESS

Wherever varieties of too late maturity are being grown, this may be overcome in several ways: (1) Securing seed of some earlier type. This may originate in the same locality or be of some previously tried variety obtained from a distance. Before a new corn is extensively substituted for an old one, definite knowledge should be had regarding its local adaptation. (2) Field selection of seed from the earlier maturing plants before autumn frosts, while such difference is readily discernible. (3) Selection of the drier and more mature ears later in the season. To a considerable extent, such ears are more mature because of inherent relative earliness. Corn may be made to average a week or ten days earlier in maturity in a very few years by such selection. It is probable that most of the corn grown in Nebraska could be made a week earlier without reducing the average yield, and the quality would be improved.

A rather arbitrary ideal of deep rough grain is held by many corn growers. This quality is usually associated with late maturity and also high shelling percentage. A mistaken conception prevails that high shelling percentage means high acre yield. To the contrary, corn with a rather medium depth kernel yields fully as much grain per acre, ripens somewhat earlier, is often of much better quality and frequently possesses stronger viability.

ALTERNATIVES IN SEED SELECTION

(1) Special, early field selection, before any likelihood of frost, may be practiced regularly each year. When such corn is stored and cured in a dry, well-ventilated place, good germination without further trouble is reasonably certain. This procedure, systematically insures sound seed corn. An essential requirement in this practice is to avoid immediate contact between the different ears so long as they are not well dried out. Thus mould and decay will be prevented. By going thru the field with a sack hung over the shoulder, or other simple device, the best developed and most matured ears may be readily gathered. Seed selected in the stiff dough stage is sufficintly mature to produce strong, vigorous plants. However, more mature seed is more easily preserved.

(2) Selecting seed late in September or early in October, while husking corn in the regular way for early hog feed, is a safe

and convenient manner of obtaining sound seed corn. Precaution should be taken to insure rapid drying and avoidance of mould. This procedure usually requires some husking before the bulk of the corn is sufficiently dry for general husking. The necessary seed for the average farm may usually be selected from several loads of this early husked corn. If this plan is systematically followed, a supply of sound corn may be fairly certain year after year.

(3) Selecting seed at the time of general husking is the most common of all methods. Either a box is attached to the side of the wagon into which the seed ears are thrown while husking, or else the seed ears are selected from the wagon while unloading. This method, and particularly the practice of picking the seed ears in the field while husking, has many commendable features in years of early maturity when a large percentage of the ears will possess strong germination even when left exposed in the field to severe freezing weather. In other years, such as 1911, 1915, and 1917, there may be such a small portion of viable ears after subjection to freezing weather, that much annoyance and difficulty is experienced in selecting them.

If necessary to select seed ears from a field where freezing injury has been severe, the rather slender, hard, solid, smooth ears with relatively shallow grains (Fig. 15) will be found most certain to give satisfactory germination. For those who do not favor this type of ear, it may be said that it is likely to yield fully as much grain to the acre as the larger, rougher types, even in years when both give equally good germination. Severe freezing destroys the viability of immature seed.

This is a factor in the natural adaptation of the crop. It tends to eliminate the later strains, while the earlier ones survive. By selecting the ears, therefore, which have withstood severe freezing in the field, more consistent earliness is developed.

(4) Corncrib selection may be practiced in an emergency as a last resort. If provision for a seed supply by other methods has been overlooked, well matured and sound seed ears may in most years be selected from the crib during the winter or spring. Such home grown seed is to be recommended in preference to imported seed whose adaptability is not definitely known.

(5) *Old Seed.* In order to insure against emergencies, it is a desirable practice to select sufficient seed in years when corn matures well for two years' planting. It seldom happens that two successive bad years occur, and by this practice much uneasiness and annoyance may be avoided in bad years. One-year-

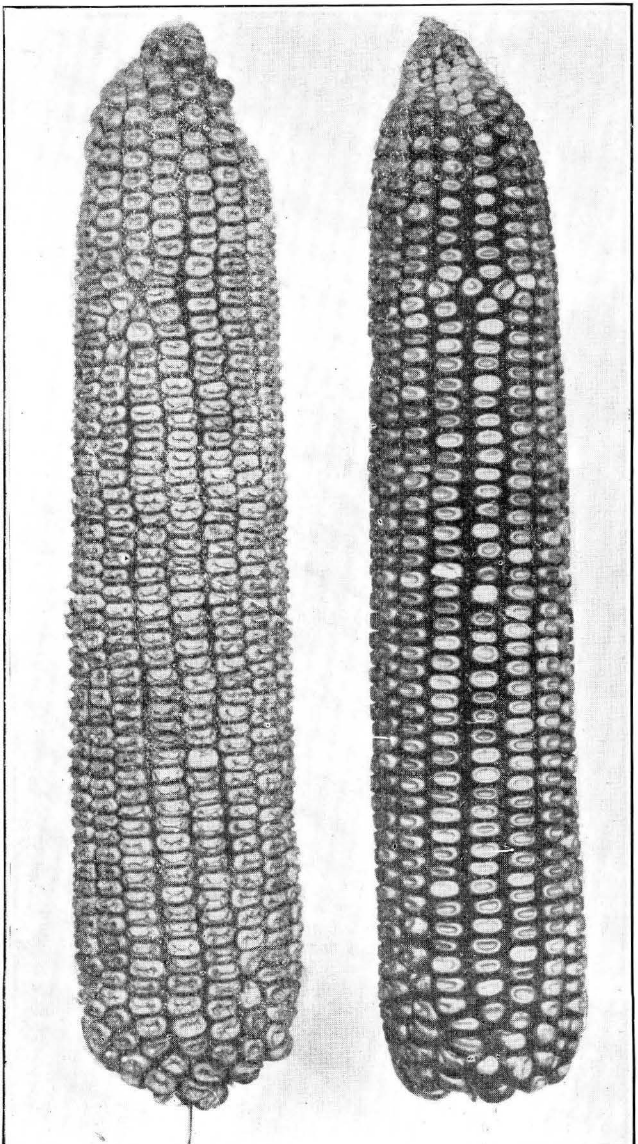


Fig. 15—Standard and smooth ear types of Hogue's Yellow Dent corn. This smooth ear with kernels of only medium depth may be relied upon as the soundest seed in such crops as grown in 1911, 1915, and 1917. It also yields fully as well.

old seed corn is entirely satisfactory if it has been well preserved.

COMBINATION OF METHODS FOR SELECTING SEED

For many farm operations, the procedure may be variable from year to year according to the seasonal conditions, or the individual farmer's fancy or convenience. This holds true in regard to the time and manner of selecting the seed corn supply. The conditions are very exceptional in which a satisfactory seed supply with apparently equal productivity cannot be selected by any one of the first three methods just described. The relative convenience and practicability of the methods may vary from year to year. In years when corn is backward, it is good practice to select seed from corn husked early, before heavy and continued freezes are to be expected. In years of early maturity, when corn is well dried out, it may be quite as well to pick the seed ears at the time of regular husking. Whether special early selection is practised in such years may be left entirely to the convenience of the farmer. However, in years when corn is late in maturing, early selection and preservation of seed corn may avoid the great annoyance of sorting over a large quantity of corn for the small percentage of sound ears that will give satisfactory germination. Early selection is probably of greater importance in the northwestern half, than in the southeastern half of the State.

ASCERTAINING VIABILITY

After the seed ears are thoroly cured, a general germination test may be made of a composite sample of kernels taken scatteringly from each of several hundred ears at the rate of about six kernels per ear. If less than about 90 per cent perfect germination is obtained, a more severe elimination of unsound ears should be made. Discarding all ears with discolored germs and the making of an individual ear germination test are rather effective methods. The making of such tests is generally understood by farmers. If germination tests are made, care must be taken to provide proper germinative conditions, in order that misleading results may not be secured.

The most reliable general test may be made by planting the seed in a box of soil. The number of seeds actually producing plants may thus be ascertained. If the tests are made between moist blotters, cloths, or by any other similar device, the kernels, after sprouting, may easily be exposed and the germination counted. With well-matured seed, only strong, vigorous sprouts

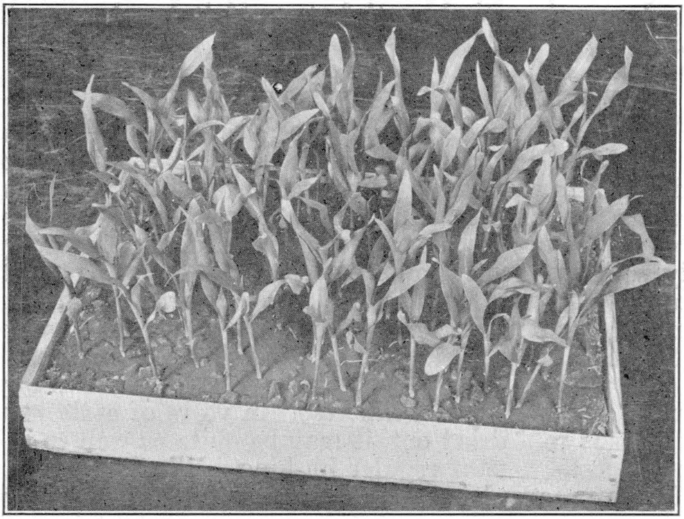


Fig. 16—A final germination test should be made to definitely determine what percentage of the seed will grow. The corn planter may then be adjusted for an average drop of the desired number of kernels

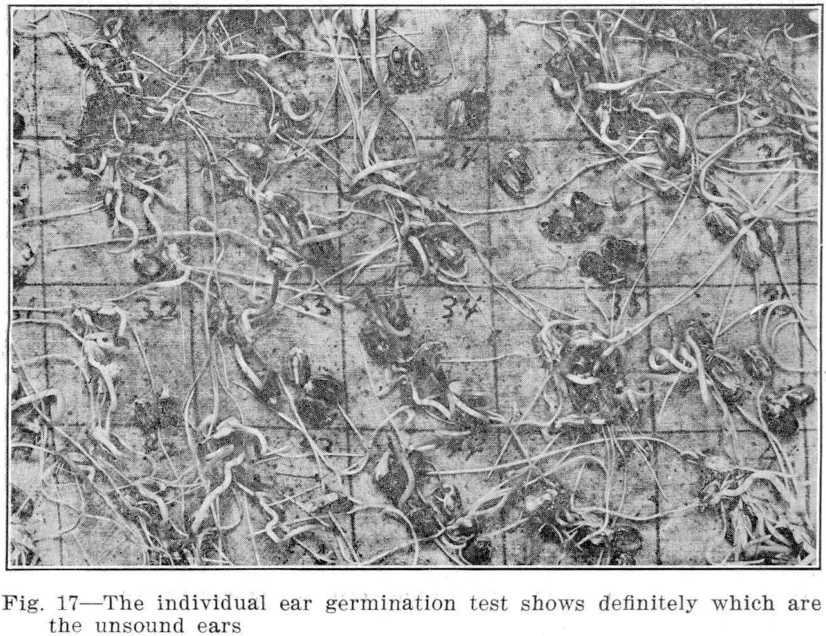


Fig. 17—The individual ear germination test shows definitely which are the unsound ears

are obtained. Where less mature corn has been subjected to severe freezing, as high as 10 or 15 per cent may germinate imperfectly. Such seed may have either the plumule or the primary root killed, while the other end of the sprout may develop normally. If the plumule has been killed a viable root can never grow a new plumule. But if the primary root only is dead, the secondary roots may, under favorable germination conditions, develop at the base of the plumule and a normal plant result. Such imperfect sprouts may be seen in Figure 20.

Germination tests are often reported as so many strong, weak, or dead kernels. It would probably be quite as well to report perfect and imperfect germination and dead kernels. Since proper development of imperfect germs is doubtful, a classification into perfect and dead seed should suffice. Perfect kernels reported as weak are often relatively backward merely because of inherent slower germination or because of ununiform, unfavorable germinating conditions which act as sources of experimental error in testing.

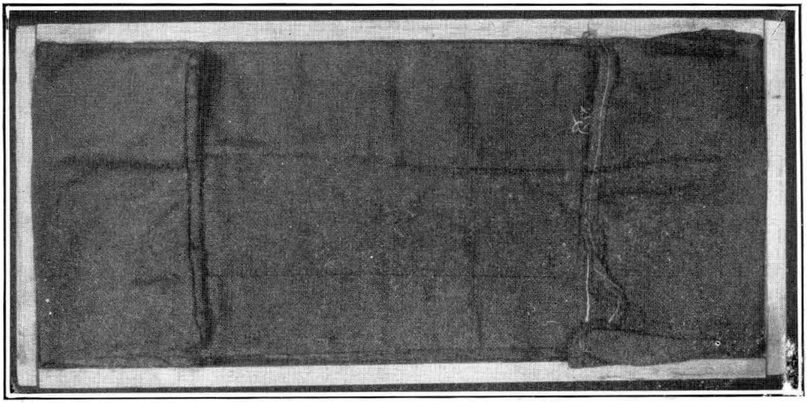


Fig. 18—Germination box filled with sawdust and covered with burlap to retain moisture

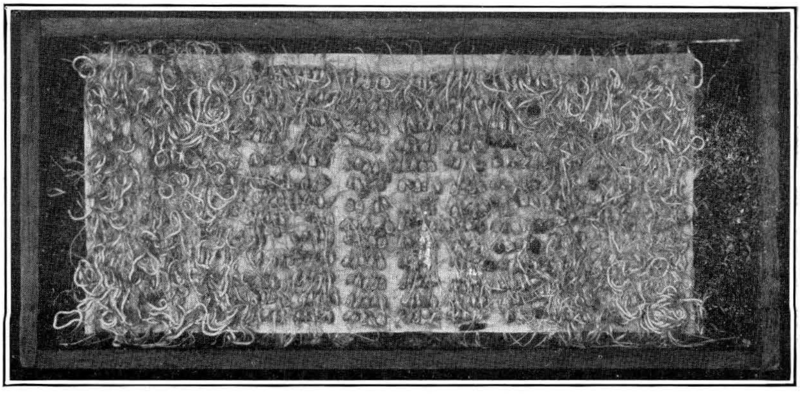


Fig. 19—The germination box shown in Figure 18, uncovered. Note the much more vigorous growth at the ends of the box where the burlap was folded back and greater pressure exerted by the box standing on top. The germinative ability of the corn at the center actually equalled that at the ends. This illustrates possible experimental error in testing for germination

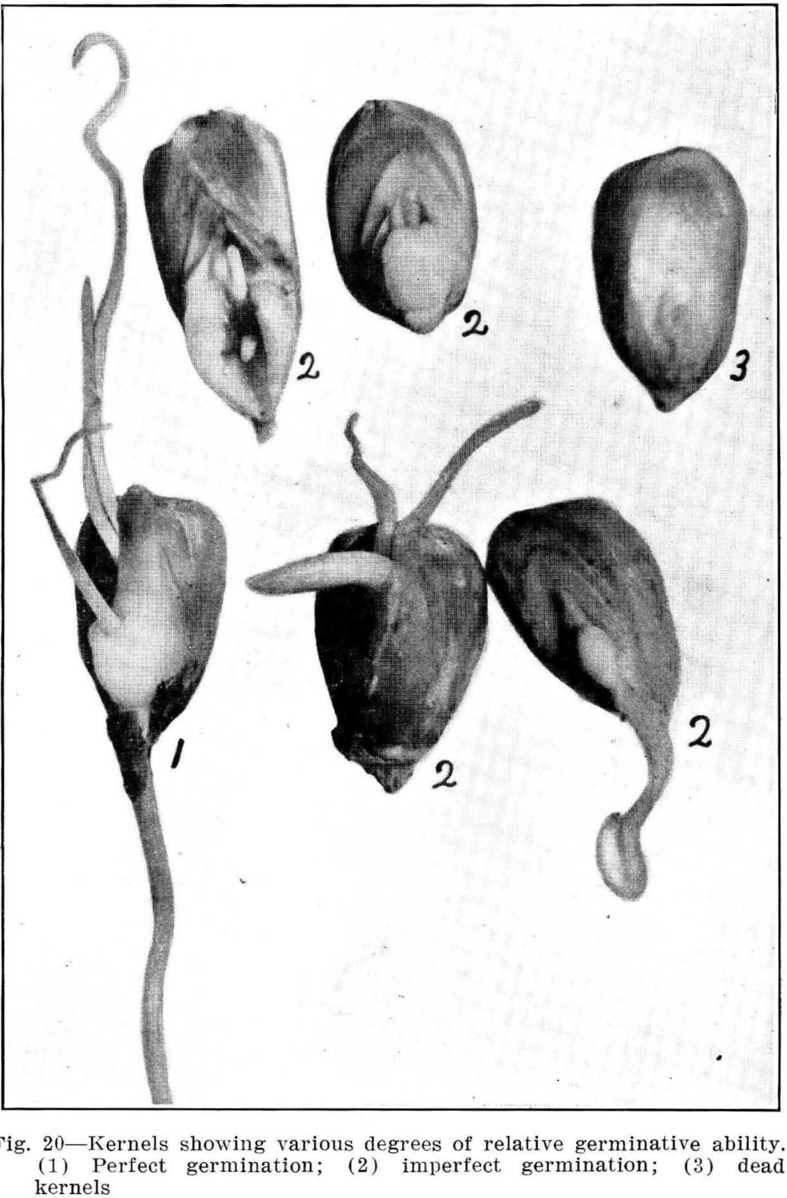


Fig. 20—Kernels showing various degrees of relative germinative ability. (1) Perfect germination; (2) imperfect germination; (3) dead kernels

RELATIVE CORN YIELDS FOR THE STATE OF NEBRASKA IN YEARS FOLLOWING SEVERE SEED CORN INJURY

The average yield of corn for the State of Nebraska during the last 28 years, 1890 to 1917, as estimated by the Bureau of Crop Statistics and the State Board of Agriculture, has been 24.9 bushels per acre. During this period, there have been three years of serious seed corn injury, namely 1896, 1911, and 1915. The acre corn yields for the State in the years following this seed corn injury (years in which the affected seed was planted) were respectively 30.0, 27.1, and 32.6 bushels. Since the yield has been above normal each year in which it was necessary to plant seed selected from corn undergoing severe winter injury, it is evident that the farmers meet the situation in a fairly satisfactory manner. The average superiority of these three years above the 28 year average has been 5.0 bushels per acre. Therefore predictions of low yields following years of severe seed corn injury do not seem justified. The actual increase in yields is probably due to accidentally more favorable climatic and moisture conditions.

EFFECT OF TIME OF SELECTION AND PRESERVATION OF SEED CORN UPON YIELD

An experiment was begun in the fall of 1914 to determine the effect of the time of harvesting seed corn upon its yielding power provided care is taken in selection to obtain equally high germination. A comparative yield test was made in 1915 of September, November, and March selections from a field of Nebraska White Prize corn. This is a standard variety grown at the Experiment Station and adapted to southeastern Nebraska. A similar test was made in 1916 and 1917 of seed selected in September, October, November, December, February, and March. The seed was carefully preserved in a dry, well-ventilated place after being harvested. After danger from freezing injury, only seed ears which showed a bright clear germ were taken. Ears with discolored germs were discarded because they promised low germination. A large number of ears were composited for each selection.

Four systematically replicated 3-row plats were planted from all selections each year. The rows were 72 hills long with hills 44 inches apart. Six kernels were space planted by hand in each hill. The stand was reduced by thinning to 3 plants per hill after growing about 2 weeks. This insured practically a full and uniform stand. The first fifty hills having 3 plants, and surrounded by a full stand were harvested from the center row of each plat for the yield test. This arrangement permitted a direct comparison of the inherent yielding capacity of the different lots. The results follow in Table 32.

TABLE 32—*Relative yields of seed corn selected at various dates during the fall and winter (1915-1917)*

Date of seed selection[1]	Duplications each year	Yield per acre				
		1915	1916	1917	Average 1916 and 1917	Three year average
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
September...	4	66.6	36.1	38.3	37.2	47.0
October.....	4	....	36.9	38.3	37.6	....
November...	4	·65.9	37.3	41.6	39.4	48.3
December...	4	....	39.3	42.4	40.8	....
February....	4	....	44.3	41.7	43.0	....
March......	4	64.7	42.1	42.6	42.3	49.8
Check[2]......	4	66.3	40.3	41.1	40.7	49.2

[1]The seed was harvested about the 15th of each month.

[2]The check seed was harvested from the same field while husking in November.

As an average for the three years 1915-1917, seed corn harvested by special selection from the field in September, November, and March, and given good care after selection, yielded respectively 48.2, 49.6, and 51.2 bushels per acre, while seed saved from the same field during the regular process of husking in November yielded 50.6 bushels per acre. We may conclude from these data that corn harvested early and given special care in preservation will not outyield seed which has been exposed to the cold of winter without special care, provided both are selected for high germinative qualities. Seed which has received no special early selection and preservation may be expected to yield as well as specially cared for seed, provided equally satisfactory stands are obtained. No claim is made, however, that seed selected late in winter will necessarily germinate as dependably as will that gathered earlier.

RELATIVE YIELDS OF DIFFERENT EAR TYPES

During the four years 1914 to 1917, four ear types of Nebraska White Prize corn have been compared in yield with the original unselected corn from which the types were selected each year. This variety has been grown at the Experimental Station many years. The method of testing was the same as that described on page 84. Basing the yields upon equal numbers of plants grown under uniform conditions enabled a fairly reliable test of the relative inherent yielding qualities. The results are given in Table 33.

TABLE 33—*Yield per acre from different ear types of Nebraska White Prize corn (1914-1917)*

Type of ear	1914	1915	1916	1917	Average
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Original	48.7	64.8	65.5	53.5	58.1
Large rough	30.0	65.3	64.4	45.9	51.4
Short rough	44.4	68.9	65.1	49.9	57.1
Short smooth	45.0	72.6	60.1	49.2	56.7
Long slender smooth	48.7	66.4	65.2	54.9	58.8
Number of duplications	6	8	14	7	

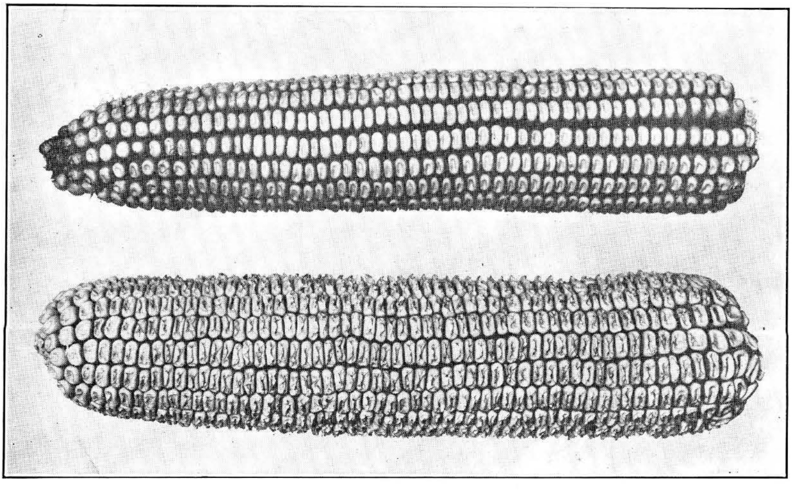


Fig. 21—Rough ear and long, slender, smooth ear of Nebraska White Prize corn. At the Experiment Station on an average for four years, the rough type has yielded 51.4 bushels, compared with 58.8 bushels for the smooth type

As an average for the four years, the long, slender, smooth type yielded 58.8 bushels per acre, which is 0.7 bushel more than the original corn, 7.4 bushels more than the large rough ears, 1.7 bushels more than the short rough ears, and 2.1 bushels more than the short, smooth ears. One may conclude that this long, slender, smooth sype possesses highly satisfactory yielding qualities, which, coupled with its superior germinative ability, makes it a very suitable type to grow. This type of ear is gaining greater popularity among corn men of the State, altho the old prejudice for deep rough ears with a high shelling percentage has been rather persistent.

EFFECT OF UNUNIFORM STAND ON YIELD

An investigation was made in 1915 and 1916 to determine the effect of varied distribution of plants upon the yield of corn. The number of plants per acre was the same in all cases, but the number of plants in adjacent hills differed. The purpose was twofold: (1) To learn the effect of variation in stand caused by mechanical variation in dropping by corn planters, when corn with perfect germination is planted. (2) To learn what result might be expected from planting corn, only part of which will grow, but for which the rate of planting has been calculated to seed the desired number of sound kernels per acre. The tests were made in duplicate 5-row blocks and equal numbers of each type of hill were harvested within each plat.

The methods of distribution compared were:

(1) All hills with uniformly 3 plants.

(2) Alternating hills with 2 and 4 plants.

(3) Alternating hills with 1, 3, and 5 plants.

(4) Alternating hills with 1, 2, 3, 4, and 5 plants. The results are given in Table 34. The average yield for the three

TABLE 34—*Effect of varied distribution of plants in planting compared with uniform distribution (1915 and 1916)*

Plants per hill	Yield per acre		
	1915	1916	Average
	Bushels	*Bushels*	*Bushels*
Uniformly 3 plants	93.4	55.2	74.3
Alternating 2 and 4 plants	89.8	58.4	74.2
Alternating 1, 3 and 5 plants	88.0	52.4	70.2
Alternating 1, 2, 3, 4 and 5 plants	95.1	54.4	74.7
Average for varied distribution	91.0	55.1	73.0

varied distributions was 73.0 bushels compared with 74.3 bushels for the uniform planting rate of 3 plants per hill. A uniform stand of 3 plants per hill yielded 1.8 per cent more than the mean for the various distributions. Variations in stand due to the planter, or to the presence of dead seed in corn testing as low as 75 per cent, is less marked than the variations in the above special plantings.

The data in Table 34 are substantiated by a very similar experiment conducted by Montgomery in 1907 and 1908, the results of which are given in Table 35. The average yield of the varied distributions in this test was 2.1 per cent lower than a uniform distribution of three kernels.

TABLE 35—*Effect of varied distribution of seed in planting compared with uniform distribution (1907 and 1908)**

Grains planted per hill	Yield per acre		
	1907	1908	Average
	Bushels	*Bushels*	*Bushels*
Uniformly 3 grains	71.2	58.9	65.5
Alternating 2 and 4 grains	70.4	56.9	63.6
Alternating 1, 3 and 5 grains	70.7	60.1	65.4
Alternating 1 and 5 grains	64.5	60.6	62.6
Average for varied distribution	68.5	59.2	63.9

*Data in Table 35 taken from Nebraska Agricultural Experiment Station Bulletin 112, by E. G. Montgomery.

EFFECT OF IMPERFECT HILLS IN CHECKED CORN

The data in Tables 36 and 37 show how the crop adjusts itself for missing plants in an otherwise uniform stand. During the two years, 1914 and 1917, a rather large number of corn hills containing either 1, 2, 3 or no corn plants were scattered systematically thruout a field of checked corn otherwise containing 3 plants per hill. By harvesting the hills separately, the effect of hills containing 1, 2, or no plants upon hills with the normal number of 3 plants could be determined. Also the relative yields of hills containing 1, 2, or 3 plants when surrounded uniformly by 3-plant hills could be determined.

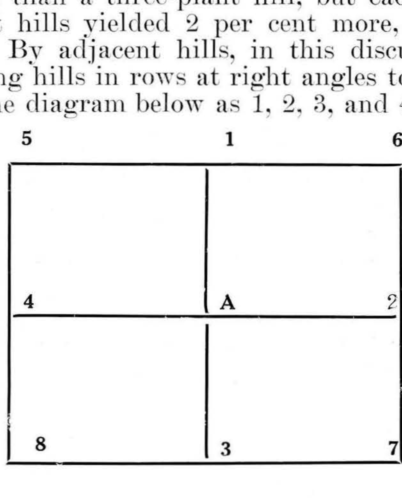
Table 36—*Relative yields of one, two, or three-plant corn hills when uniformly surrounded by three-plant hills. Nebraska White Prize corn (1914 and 1917)*

Number of plants in hills surrounded by uniform 3-plant hills	Total number hills averaged	Number of ears per 100 plants	Average grain yield per hill	
			Actual	Relative
			Pounds	
Hills with 3 plants	598	89	1.073	100
Hills with 2 plants	120	99	0.883	82
Hills with 1 plant	80	141	0.656	61

Table 37—*Relative yields of three-plant corn hills when adjacent to hills with various numbers of plants. Average for 1914 and 1917*

Three-plant hills surrounded by 3-plant hills except as indicated below	Total number hills averaged	Number of plants per hill	Number of ears per 100 plants	Average grain yield per hill	
				Actual	Relative
				Pounds	
Surrounded by hills with 3 plants	598	3	89	1.075	100
Adjacent to 1 hill with 2 plants	360	3	91	1.098	102
Adjacent to 1 hill with one plant	302	3	94	1.151	107
Adjacent to 1 blank hill	366	3	94	1.224	114

As an average for the two years, the two-plant hills yielded 18 per cent less than a three-plant hill, but each of four adjacent three-plant hills yielded 2 per cent more, due to the one missing plant. By adjacent hills, in this discussion, is meant the 4 surrounding hills in rows at right angles to each other and designated in the diagram below as 1, 2, 3, and 4.



A one-plant hill yielded 39 per cent less than a three-plant hill, but on account of the two missing plants the yield of each of the four adjacent three-plant hills was increased 7 per cent thus recovering nearly three-fourths of the loss.

A no-plant hill yielded nothing, but each adjacent three-plant hill yielded 14 per cent more due to the three missing plants.

To sum up.—50 per cent of the yield lost in a hill with one missing plant was recovered in the four nearest adjacent hills; 72 per cent of what was lost in a hill with two missing plants was recovered in the four nearest hills; 56 per cent of what was lost in a hill with no plants was recovered in the four nearest adjacent hills.

While our experimental data show the effect of incomplete hills upon only the 4 nearest adjacent hills located at right angles, it is quite likely that the recovery extends at least to and possibly beyond the 4 nearest diagonal hills also indicated in the diagram at 5, 6, 7, and 8.

The fact that the yield is not greatly reduced by an ununiform distribution of the plants (within reasonable limits) may be explained by the large feeding area of the roots of a corn plant. A corn hill is not limited to its own 3 feet 8 inches of land, but may laterally draw considerably beyond its adjacent neighboring hills for water and plant food material. Since these materials are usually limiting factors, a relatively greater abundance made available by one or more missing plants goes to increase the yields of other plants.

If a hill with one or two missing plants was partly surrounded by hills containing only a partial stand, it would not be reduced in yield to the same degree as when fully surrounded by 3-plant hills, because the competition would not be so large.

PROBABLE DISTRIBUTION OF PLANTS WHEN SEED OF LOW GERMINATION IS PLANTED

Every farmer has in mind some rather definite spacing of plants in the field which he regards as an optimum planting rate for his locality in the average year. Various experiments have indicated that there may be some variation in the planting rate without a material effect upon the yield.

Rather than to procure imported, unadapted seed with perfect germination in years of seed corn injury, locally grown adapted seed testing as low as 75 per cent, or 65 per cent should be used if sounder seed cannot be selected. When the test is

TABLE 38—*Showing chance distribution of plants when seed germinating 75, 65, and 50 per cent is planted in hills 44 inches apart*

Where corn germinates 75 per cent and 4 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
4 sound	31.588	1,024
3 sound, 1 dead	42.258	1,370
2 sound, 2 dead	21.105	684
1 sound, 3 dead	4.664	151
4 dead	0.385	12
Total	100.000	3,241

Where corn germinates 65 per cent and 4 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
4 sound	17.845	578
3 sound, 1 dead	38.455	1,246
2 sound, 2 dead	31.059	1,007
1 sound, 3 dead	11.144	361
4 dead	1.499	49
Total	100.000	3,241

Where corn germinates 50 per cent and 5 kernels are dropped per hill

Seed dropped per hill	Per cent such hills	Total number such hills per acre
5 sound	3.122	101
4 sound, 1 dead	15.622	506
3 sound, 2 dead	31.256	1,013
2 sound, 3 dead	31.256	1,013
1 sound, 4 dead	15.622	506
5 dead	3.122	101
Total	100.000	3,240

below 85 an allowance should be made for the dead seed in the rate of planting.

By using partially unsound seed, a uniform stand cannot be obtained. But it has been shown that absolute uniformity is not necessary for maximum yields. An application of the law of chance (Table 38) shows how the sound kernels will be distributed when seed testing 75 per cent, 65 per cent, and 50 per cent is used with an approximate adjustment in the planting rate to compensate for the reduced germination.

The chance combinations of sound and dead seed per hill in Table 38, are calculated from the following formula:

The probability of dropping p sound kernels and q dead kernels from a composite sample containing m sound kernels and n dead kernels is:

$$\frac{m'}{(m-p)'} \cdot \frac{(m+n-p-q)'}{(m+n)'} \cdot \frac{n'}{(n-q)'} \cdot \frac{(p+q)'}{p'\,q'} \quad \text{where}$$

$m' = m\,(m-1)\,(m-2)\,(m-3)\ldots\ldots 3, 2, 1$ = product of all intergers from 1 to m.

Acknowledgment is made to Prof. Carl Engberg, for supplying this formula.

For purpose of illustration, it will be assumed that approximately the rate of three sound kernels per hill is desired. The hills are spaced 44 inches apart. An acre contains 3,241 such hills.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 75 PER CENT

If the corn tests 75 per cent and a stand of 3 plants per hill is desired, then 4 kernels should be planted per hill. The average hill will contain three sound and one dead kernel, but they will not be uniformly distributed. On the other hand, 31.6, 42.3, 21.1, 4.6, and 0.4 per cent of the hills will contain 4, 3, 2, 1, and no plants respectively. In an acre with 3,241 hills there will be 1,024 hills with 4 plants, 1,370 hills with 3 plants, 684 hills with 2 plants, 151 hills with 1 plant, and 12 hills without plants.

Results almost identical with the above calculation were obtained in an actual test with 1,500 hills, each of which contained 4 kernels taken at random. In this test 31.3, 41.6, 22.7, 4.1 and 0.13 per cent of the hills contained respectively 4, 3, 2, 1, and no plants as compared with 31.6, 42.3, 21.1, 4.6, and 0.4 per cent for chance calculations. For purposes of this study, the dead kernels were white and the sound kernels were yellow, which per-

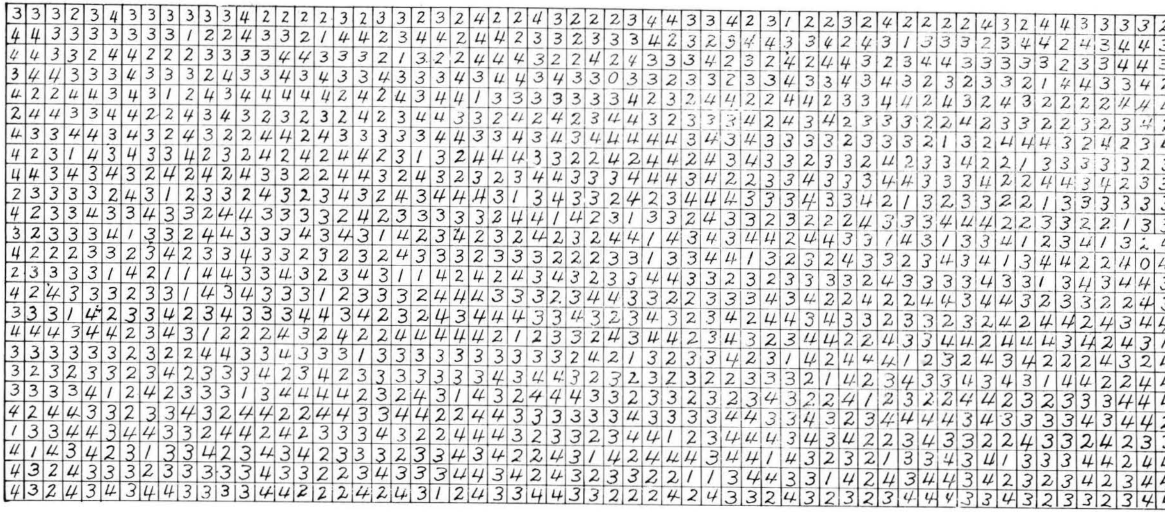


Fig. 22—Actual distribution of sound kernels in hills when four kernels were taken at random for each hill from seed germinating 75 per cent

mitted correct separation. Figure 21 shows how these hills arranged themselves by chance in 25 rows of 60 hills each.

It is understood that this and the two following examples are illustrative and would be varied somewhat in farm practice for the reason that a planter cannot be set to always drop a uniform number of kernels per hill.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 65 PER CENT

If corn testing 65 per cent germination is planted at the rate of 4 kernels per hill, then 17.8, 38.5, 31.1, 11.1, and 1.5 per cent of the hills respectively will have 4, 3, 2, 1, and no plants. An acre containing 3,241 hills will have 578 hills with 4 plants, 1,246 hills with 3 plants, 1,007 hills with 2 plants, 361 hills with 1 plant, and 49 hills with no plants. The no-plant and one-plant hills are likely to be distributed among the others in such manner that little reduced yield per acre need be expected.

By planting seed with a viability of 65 per cent at the rate of 4 per hill, 87 per cent as many plants per acre should be expected as when 75 per cent viable seed is planted at the same rate.

DISTRIBUTION OF SOUND KERNELS WHEN SEED TESTS 50 PER CENT

If corn is planted 5 kernels per hill, only half of which will grow, an acre will contain 101 hills with 5 plants, 506 hills with 4 plants, 1,013 hills with 3 plants, 1,013 hills with 2 plants, 506 hills with 1 plant, and 101 hills with no plants. The average rate per hill for such planting is 2½ sound kernels. The yield to be expected from such a distribution of plants should be fairly satisfactory. However, there seems little need for planting corn with so low a test.

(2M)

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