SOME EFFECTS OF COLD ON THE FLOWER PRIMORDIA OF STRAWBERRIES

by

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INTRODUCTION

Reduced yields and non-fruitfulness have long been noticed in strawberries but have not usually been associated with low winter temperatures. Many growers have believed that non-fruitfulness has been due in large part to late spring frosts killing the blossoms.

A peculiar malady troubling the mid-western grower is an apparent blighting of strawberry flower clusters, or "blasting" as it is frequently called. Webster defines blighting as any disease, symptom of disease, or injury of plants resulting in withering, cessation of growth, and a more or less general death of parts such as leaves, flowers, stems, etc., without rotting. The same source defines blasting as an obsolete form of the word blighting, and adds that the term blighting is frequently accompanied by another word when used in describing a specific pathogenic agent.

The term blighting will be used in this paper to denote a specific condition observed in the blooming strawberry plant, thought to be caused by cold injury. The condition is described later in this paper.

Filinger (1941) reporting on the 1941 strawberry crop, said:

> Some of these damaged strawberries (plants) died during the winter but many survived and produced blossoms in the spring of 1941. The damage, however, showed up in the resulting fruit clusters. The terminal fruits which should produce the earliest fruits were blasted. Next, lower fruits were

small or deformed, so the only berries produced were from the lowest buds on the clusters.

Abmeyer (1941) reported the same crop as only about half normal, and "very small and knotty."

The principal purpose of this study was to investigate some of the effects of cold on the flower primordia of the strawberry. Other factors investigated were the effects of cold on various plant parts such as roots, crown, and stem tissues. These tissues were studied in an effort to determine if any correlations existed among the various plant parts with their relative susceptibility to injury from low temperatures.

LITERATURE REVIEW

Aside from periodic descriptions of frost injury to flowers, few literature references to winter injury of strawberry flower buds could be found. As pointed out by Darrow (1951), Waldo (1951), and Armstrong (1942), damage to flower buds is thought to occur without lethal injury to the plant.

In any study of this type it becomes necessary to consider some of the factors related to winter injury. Death of plants due to low temperatures has been studied extensively. Some of the theories of the causes of death from freezing include the formation of ice crystals in the intercellular spaces, precipitation of the proteins, rupturing of the protoplasm by the ice crystals, and increased cell sap concentration. Schaffnit and

Ludtke (1932) consider the death of a plant from frost or heat a problem of metabolism. The entire process of metabolism need not be suspended. The cessation of the activity of only one enzyme may be sufficient to cause death according to them.

Courley and Howlett (1949) point out three factors concerned with the amount of injury from freezing. They are the duration of low temperature, the rate of the temperature fall, and the rate of thawing.

Filinger (1942) found that many plants survive "test winters" without apparent injury but that sudden rapid lowering of temperatures such as occurred throughout the mid-west on November 11, 1940, causes extensive damage at much less severe temperatures.

Chandler and Hildreth (1936) report:

> Yellow Newton apple twigs were badly damaged by being moved directly from air at 20° C into sodium chloride solution at -12° C and left 11 minutes. There was no damage to other twigs left 25 hours in the same solution in a warm room or to others cooled slowly in air to -17° C and left 4 hours.

Campbell (1948), reporting on the survival of peach trees after exposure to -32° F stated:

> Although the temperature fell rapidly on January 3 and 4, the killing of the tissue might have been greater but for the protracted period of near zero weather immediately proceeding this big drop in temperature.

From this statement one might assume that rapid temperature drops have little effect after the plants are well hardened by prolonged exposure to cold temperatures.

Gourley and Howlett (1949) point out that the rate of thawing may or may not be a factor in the amount of killing as it is frequently observed that shaded or protected leaves or fruits are damaged less than those exposed to bright sunlight immediately after the low temperature period. This idea is disregarded by some who argue that the rapidity of thawing is immaterial due to the fact that the lethal damage was due to processes occurring before thawing.

Resistance of plants to freezing injury has been another subject of much research. Harvey (1930), working with cabbage seedlings, found that exposure to periods of cool temperatures, above freezing, increased a plant's ability to withstand freezing temperatures. He suggests a "threshold" temperature of 5° C at which point the chemical and physical changes occurring during the hardening process begin. He also found that plants exposed to alternating temperatures between 0° and 10° C hardened more than those held at a constant 5° C. The duration of the cold period in the alternating temperature treatment could be as little as two hours and still the benefits of alternating over constant temperatures were observed.

Angelo (1939) found that strawberries hardened in the laboratory at alternating temperatures of 0° C and 20° C for seven days attained their maximum hardiness. He also found that plants well watered hardened less than plants kept dryer while hardening.

The changes that take place in the plants during the hardening process which enable some plants to survive extremely low winter temperatures have been widely studied. Some of these are thought to be increased concentration of the cell sap, decrease in moisture content of the cell sap, increase in "bound water" of the colloidal system, and conversion of some of the cell sap constituents to forms less likely to injure the protoplasm on increased concentration from withdrawal of water by freezing.

Scarth, according to Bonner and Galston (1952) indicates that hardening is linked primarily with the mechanical properties of the protoplasm. When tissues are hardened, they become more resistant to mechanical damage by plasmolysis and deplasmoysis. This resistance to mechanical damage is also associated with increased permeability of the plasma membrane. These physiological changes are accompanied during hardening by two major changes in the chemical composition of the plant. The osmotic pressure increases, sometimes double that of the unhardened cell. This is a factor in cold hardiness, since through the increase in osmotic pressure, the freezing point of the tissue is lowered. At the same time, the concentration of tissue protein increases sharply to a value two or more times that found in non-hardened plants.

Martin (1927) indicated that during the hardening of wheats there is a decrease in moisture content, an increase in total solids in the sap, and an increased osmotic pressure and imbibition pressure of colloids as measured by the ability of the tissues to hold the sap against the forces of freezing or pressure as applied in a plant press.

Various tissues harden to different degrees of cold resistance. This is evidenced by plants that show differential tissue killing in such a way as to survive serious injury from low temperatures. Filinger (1942) and Gourley and Howlett (1949), have described differential killing of the same type of tissue at different locations on the plant. The latter point out that different tissues under proper conditions harden to different degrees of hardiness. They list the tissues in order of hardiness as cambium, phloem, bark, cortex, and pith.

Macoun, according to Gardner, Bradford, and Hooker (1939), indicates that nine of ten forms of winter injury appear above ground. They also suggest that winter killing may depend on: (1) lack of maturity in tissues, (2) lack of ability to resist winter drought conditions, (3) too ready response to short periods of warm weather in the winter.

The same authors proceed in their discussion to point out that summer and fall conditions preceding the winter contribute greatly to tissue maturity. Warm moist autumns keep tissues growing, and hence little hardening occurs. During dry cool falls, the tissues mature well and become well hardened before any seriously cold weather arrives. Often "second growth", induced by dry summers and fair precipitation in early autumn, may result in immature tissue at entrance into winter.

Miller (1938), and Gardner, Bradford, and Hooker (1939), point out that plants often suffer from dessication due to physiological drought induced by frozen soil in which they are growing. The former states that winter cereals are often damaged by this type of injury, contributing to their later death by freezing. Gardner, Bradford, and Hooker (1939) state:

> In many sections there is seldom if ever a time when soil moisture would be a limiting factor in this connection. In others it is frequently a limiting factor and gives rise to those injuries that are associated with winter drought.

Darrow (1937) suggests winter drought as a major factor in winter injury to strawberries, especially in the Central Plains states.

The morphology of the strawberry plant probably assists it to stand cold temperatures without serious injury. White (1927) describes the strawberry crown as "a short fusiform body" growing so close to the ground that it is often half submerged in the soil. He continues:

> It may later, by apical growth, become cylindrical and eventually fork into two or more divisions. The subterranean portion is covered with adventive roots. Above ground it is clothes with leaves, the base of each of which closely encircles it for some three fifths of its circumference.

White (1927) also found the anatomy of the plant well adapted to recovery from damage, be it mechanical, biological, or physical. He describes it as follows:

> In the crown, on the other hand, the entire vascular cylinder is made up of short, anastomosing bundles which provide an efficient means of rapid transfer of water and solutes across the stem. Moreover, the bundles themselves, instead of being made up of long vessels, are composed of short tracheids provided with large lateral and terminal pores which further increase the efficiency of cross as well as longitudinal transfer of water. Such a crown structure

> makes it possible for plants which have had most of their roots cut by hoe or an insect to supply all leaves, runners, and other parts uniformly with water and nutrients. Reduction of any part of the root system affects the plant as a whole rather than one side alone.

Such an adaptation of a plant to its environment would obviously enhance the chances for its recovery from cold winters. The low growth aids it in being covered by trash and debris for protection from the cold. Indeed, Colby (1942) states that leaves themselves are thought to be all the mulch necessary in some regions. Such a morphology might aid the plant to recover from damage by cold. Partial killing of certain tissues would not mean fatal injury. Adventive roots can apparently be sent out from any point of the stem, and if older roots are injured by cold, the plant responds by sending out new ones.

Except for reports of frost injury to strawberry blossoms in the field, and reports of the relative cold resistance of several varieties of strawberry plants by Angelo (1939), and Steel, Waldo, and Brown (1934), little is to be found in the literature relative to the effect of cold on the flower buds of the strawberry. Havis (1938), Shoemaker (1948), and numerous other authors have described late spring frost damage to strawberries. The damage described included complete killing of the flowers, and killing of only the receptacles of the flowers, but no description of damage such as blighting. Waldo (1951) suspected winter injury in 1951 when he found abnormal amounts of pistillate flowers.

Another type of damage attributed to cold is misshaped fruit often called "cat faces", "monkey faces", or "buttons". Havis (1938) stated that this damage was extensive in Ohio in 1938. He attributed the injury to temperatures of just below freezing while the flowers were in full bloom. He stated that the ovules of the achenes were just about as hardy as the tissues of the receptacle, and not all parts of these tissues were killed, resulting in misshaped berries at harvest. He suggested that the probable order of increasing hardiness of different tissues of the blossom was the anther, petals, filaments, pistils, and receptacles. Filinger (1942) thought "catfaces" were caused by winter injury in 1940.

Nitsch (1950), working with strawberries, found that fertilized achenes produce some auxin that stimulated the development of the receptacle or "fruit". By removing the fertilized achenes from part of the fruit when the fruit was partially developed, it was found that the fruit quit developing, and misshaped berries were produced. This same effect would obviously be produced when only partial fertilizatiön was attained.

Armstrong (1950) found in Kentucky that large amounts of "cat faces" were produced by the Tarnished Plant Bug. Material reduction of the number of misshaped berries was attained by application of cholrodane dust shortly after bloom time.

Darrow (1951) stated that Yaeger of North Dakota had selected seedlings whose blooms would withstand 18° F without injury. There seems to be a wide variation in varietal resistance to frost damage in full bloom. Havis (1938) lists the following varieties in order of tenderness of bloom: Catskill, Premier, Fairfax, Blakemore, Aberdeen, Dunlap, and Chesapeake. This might have had some correlation with the date of blooming. Unpublished Kansas data (1951) indicated the following in order of tenderness: Catskill, Temple, Fairpeake, Midland, Tennessee Shipper, Premier, Tennessee Beauty, Maytime, and Blakemore. It has been repeatedly reported that the flowers of Blakemore are very hardy which undoubtedly contributes to its adaptability to a wide range of regions within the United States.

Cold injury to blossoms in the fully dormant condition has been suspected by Darrow (1951), Shoemaker (1951), Colby (1951) and Brierley (1951). Armstrong (1942), reporting on the 1940 crop in Kentucky, stated:

> Soon after growth started in 1940 it was evident that a great many plants in the unmulched or late-mulched plots and in spring-mulched open fields were not going to blossom. This condition was chiefly noticeable in the Aroma variety.
>
> This condition had previously occurred in seasons following cold winters, (such as in 1936). It had not been associated with the weather of the previous winter. The non-bearing plants had been locally referred to as "he plants" and the variety had been accused of "running out". Thus it was shown by observations and records in 1940 that it was winter killing of fruit buds that caused so many non-bearing plants of all sizes and location in the row in late mulched fields, following severe winters.

Mulching has long been practiced but according to Colby (1942), many growers contend that the leaves are mulch enough. He stated that at the Illinois station three inches of wheat straw mulch was the best of many materials when all factors were considered. There was some crown injury even under six inches of wheat straw.

Reduced yields from winter injury has been shown on numerous occasion. Unpublished data of the Kansas Station (1947) indicate that proper mulching increased yields 11 percent on plants in the second crop year and 16 percent on first crop yields. Other data from this station indicated that mulch may be applied too early in the winter. Early December was apparently the most satisfactory. Earlier applications reduced the yield, apparently from smothering of the plants. Colby (1942) concluded that mulch should be applied before the air temperatures drop to 18° to 20° F. This author continued to say:

> Varietial resistance to cold injury was found to be consistent throughout our different mulching treatments. Premier was the most resistant, followed by Dorsett, Aroma, Redheart, Catskill, and Fairfax in descending order.

Angelo (1939) found under Minnesota conditions the varietial hardiness order to be Aroma, Dunlap, Premier, Missionary, Klondike, Progressive, Chesapeake, and William Belt. Angelo (1939), and Brierley and Landon (1944) suggested that 20° F was the danger point for cold injury to plants, and mulching before temperatures reached this point was recommended.

Angelo (1939) stated that injured plants are easily identified by sectioning. The first area to show injury is the medulla. This area of pith was thought to be the least hardy of the tissues. He stated that the greater the browning, the greater amount of damage the plant had sustained. This observation was also made by Colby (1942).

Closely allied with this type of injury is root killing. Roots at times appear to be more tender than the medulla.

Root killing has been reported by Gourley and Howlett (1949), and Waldo (1951). This damage seems to first strike the younger feeder roots, and progresses toward the older roots as the damage becomes more severe. The former state that much of the so-called "blackroot" is a result of low temperatures.

It would seem that the weather previous to extreme cold will largely determine the amount and kind of damage to the strawberry plant.

MATERIALS AND METHODS

This study was conducted in two phases. Field studies were made to learn the effects of varying times of the application of mulch on the survival of strawberry primordia and plants. Greenhouse experiments were carried on to learn what effects different hardening treatments and artificially induced cold temperatures had on flower buds, plants, and ultimate yields.

The plants in both studies were divided into lots. Each lot number was assigned chronologically as that group of plants was placed in the greenhouse under observation. They are as follows:

Lot Assignments

Lot No.	Study	Date placed under observation
1	Greenhouse	November 1, 1951
2	Field	November 8, 1951
3	Field	December 1, 1951
4	Greenhouse	December 6, 1951
5	Field	January 3, 1952
6	Greenhouse	January 5, 1952
7	Field	January 8, 1952
8	Field	February 2, 1952
9	Field	March 17, 1952
10	Greenhouse	March 30, 1952

Lots 1, 2, 4, and 5 were later dropped from the study. Lot 1 did not have the rest period broken and failed to make satisfactory growth. Lot 4 was damaged in storage and failed to grow when placed in the greenhouse. Lots 2 and 5 were dropped because of non-application to the study.

Field Studies

On November 23, 1951 plots of the Premier and Blakemore varieties were laid out at the Northeast Kansas Horticulture Experiment Fields near Blair. These varieties were selected because of their importance in Kansas. The purpose of the plots was to study the effect of different times of application of three inches of wheat straw mulch on the survival of the flower buds and plants of the two varieties. Mulches were applied on November 22 and December 22, 1951, and February 1, 1952, corresponding to the usual practices of the growers in the area. A fourth plot for a check was left unmulched the entire winter. Each sampling area which was considered as a replication consisted of six feet of row. The sampling areas were selected at random and each treatment was replicated three times.

Sampling

Samples for observation were taken in the following manner. Ten to twelve plants were selected at random from each treatment replication on the following dates: November 22, 1951, January 5, February 1, and March 17, 1952. The three replicates of each treatment were combined because of the number of plants of each sample. The plants were dug with roots as undisturbed as possible. All samples were taken to the Horticulture laboratory as soon as possible for observation.

In the laboratory, the plants had the surplus soil washed from their roots, and were "heeled out" in the plant propagation beds of the horticulture greenhouses.

Sectioning

Individual plants were selected at random for sectioning. These were rewashed and examined externally for signs of winter injury, including dead roots, extend of foliage killing, and the amount of browning in the crown.

The plants were sectioned according to a method suggested by Darrow (1951) with modifications by the author. It consisted of slicing the plant longitudinally by freehand with a razor blade after trimming off the roots and green leaves.

Each half of the plant was then observed under a Spencer Binocular Dissectiscope where the flower primordia was observed. The dissection usually cut the flower primordia in half, making the buds easy to inspect. All but the smallest buds were visible to the naked eye, so the low power of the microscope magnified all materials to a large size. If sectioning did not expose all parts of the flower bud, a small sectioning scalpel was used to remove successive layers of tissue until all parts of the bud were exposed. Dead tissue oxidizes quite quickly and all dead or damaged tissue was readily recognized. Each observation was recorded for later data compiling.

Photography

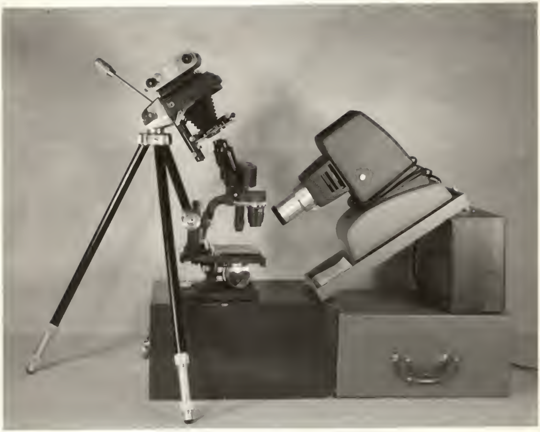
Pictures of typical types of damage were taken by a Ziess Ikon camera with a Ziess Tessar F. 4.5 lens. The camera was equipped with ground glass focusing. The lens of the camera was placed close to one ocular of the microscope while the other oscular was spread away for monocular arrangement of the material. (Plate I). Kodachrome pictures were made in the same manner with a Kodak 35 adapter for the same camera.

The same camera was used for photography of gross specimens and damaged flowers. It was equipped with a double extension

PLATE I

Arrangement of Camera, Dissectiscope, and Slide Projector used in taking Photomicrographs.

PLATE I



bellows for close range or high magnification pictures.

Greenhouse Observation of Field Samples

Ten plants of each sample of plants collected from the field plots were planted in soil in greenhouse flats, 20 plants to the flat, and placed on a raised bench.

Daily observations of the development of the plants and flowers were made. Records including the production of flowers, fruit, and plants were taken. Particular attention was paid to detect any abnormalities in the flowers and developing fruit.

Field Observations

Field observations of the plots were made on April 16, May 5, and May 12, 1952. The observations made on April 16 were made shortly after growth had started and the mulch had been removed. Plant mortality counts were taken on this date by counting the plants in randomly selected 12 inches of row that had not been disturbed by sampling as described above.

Flower counts were made May 5 and 12. These were made by counting all open blooms from 12 inches of row selected at random. At the same time the recovery of the variety plots from the winter was noted, each replication being rated arbitrarily from one to seven. The rating was based on a combination of factors including plant mortality, amount of blooms, and foliage growth.

Photographs were made of representative types of injury observed in the field.

Greenhouse Studies

The varieties Blakemore, Premier, Senator Dunlap, and Sioux were chosen for these studies. Blakemore and Premier were chosen for reasons mentioned previously. Senator Dunlap is quite popular in home gardens throughout the Mid-west. The Sioux variety is a recent release of the High Plains Regional Station, U.S.D.A., Cheyenne, Wyoming, developed to withstand the cold dry winters of the plains states.

Plants of Lots 4 and 6 were purchased from the Allen Strawberry Nursery, Salisbury, Maryland. Immediately upon arrival, a random sample was selected and sectioned according to methods previously described to determine if the plants were free from winter injury. They were then placed in cold storage at 34° F to complete the rest period.

Lot 4 was attacked by rot in storage and had to be discarded except for trial experiments. Lot 6 was planted in greenhouse flats, 20 plants to the flat.

The plants were planted in the flats on January 10, 1952. After planting, the flats were placed on a raised greenhouse bench. The temperature of the greenhouse was held at 65° F during the day and 55° F at night.

Treatments

Lot 5. Angelo (1939) and Colby (1942) found temperatures lethal to strawberries to be about 18° to 20° F. Some survived temperatures of 10° F. Darrow (1951) indicated that flowerbuds were thought to enter the winter in a more hardened condition and hence were less easily damaged by early winter low temperatures. Angelo (1939) reported that 7 days' hardening of strawberry plants at alternating temperatures of 12 hours each at 0° and 20° C produced maximum hardiness. Constant 0° C exposure hardened the plants to some extent.

Three hardening treatments, of 0, 7, and 14 days' duration were given the plants of Lot 6. The plants were hardened in the Horticulture department Cold Storage room. A thermograph indicated a temperature of 32°-34° F was maintained.

After hardening, one flat of each variety and hardening treatment was exposed to a temperature of 12°, 18° or 24° F for 14 hours. This exposure was carried out in the cold chamber in the Plant Research Laboratory. The temperatures of exposure were maintained to a ±1° F. Thermograph records indicated an even closer temperature control. After treatment the plants were replaced in the cold storage room for 24 hours for slow thawing and then moved to the greenhouse for observation. No non-hardened plants were treated at 12° F because it was felt that all would be killed, and hence show nothing of flower damage.

After treatment, the plants were replaced in the cold storage room at 34° F for 24 hours before being placed on the raised bench in the greenhouse.

Daily observations and data were recorded on the progress of the plants after being placed in the greenhouse, with particular attention paid to the quality and quantity of the blossoms produced.

Lot 10. It was observed that the non-hardened plants of Lot 6 were damaged less than those hardened. Angelo (1939) stated that plants exposed to cold in darkness failed to harden. It was also observed in Lot 6 that 18° F appeared to be the danger point in temperature, as also indicated by Angelo (1939) and Colby (1942).

Lot 10 plants were hardened in the same manner described previously, except that they were exposed to a 12 hour light day while hardening. This was accomplished by hanging 250 watt incandescent lights 18 inches above the plants. Aluminum reflectors intensified this light. The lights were controlled by a General Electric time clock switch set to turn on at 6 AM and off at 6 PM. The close proximity of the lights raised the temperature during the light period to 55° F, thus attaining the alternation temperature indicated by Angelo (1939) and Harvey (1930) to be superior to constant temperatures in hardening.

All plants were kept well watered after treatment and daily observations of both plants and blooms were recorded.

PRESENTATION OF DATA

Criteria used for measurement of the effects of cold on the flower buds would necessarily involve such items as; (1) the number of plants found with dead or damaged buds, (2) the number of normal flowers each plant produced after treatment, and (3) the number of plants observed without blooms or with injured blossoms.

Field Studies

The method of study of the effects of cold on strawberries in the field has been pointed out previously. The number of plants observed with dead or damaged flower buds appears in Table 1.

Table 1. Number of plants with dead or damaged flower buds observed during sectioning.

Variety and lot number	Treatment[1]			
	A	B	C	D
Blakemore				
Lot 3	5			
Lot 7	3	1	5	
Lot 8	2	2	2	
Lot 9	1	1	6	3

Table 1 (concl.)

Variety and lot number	Treatment[1] A	B	C	D
Premier				
Lot 3	7			
Lot 7	7	9	3	
Lot 8	1	3	7	
Lot 9	2	4	5	8

[1]Treatments A, B, C, and D refer to dates of application of mulch; A, mulch applied Nov. 22; B, mulch applied Dec. 22; C, mulch applied Febr. 1, and D, unmulched check.

The analysis of variance for these data is as follows:

Table 2. Analysis of variance of data from Lots 3, 7, 8, and 9.

Source of variation	d. f.	s. s.	m. s.
Between varieties	1	30.7	30.7*
Treatment comparisons:			
A vs B	1	.75	.75
A+B vs C	1	10.01	10.01
A+B+C vs D	1	12.57	12.57
Lot 7 vs Lot 8	1	8.33	8.33
Between untreated plots	1	4.50	4.50
Other comparisons	5	14.84	2.97
Variety X treatment	10	44.30	4.30
Total	21	126.00	

*F .05 (1,9) = 5.12.

The following statements are validated by the data given:

1. No difference in the number of plants with dead or damaged flower buds could be detected when comparing mulched with unmulched plots.

2. No difference in the number of plants with dead or damaged flowers could be detected based on the three different mulching dates.

3. The number of dead or damaged flower buds was significantly greater in the Premier variety than the Blakemore variety.

4. Plants over one year old were damaged to a highly significant greater amount than young plants set as runner plants in 1951.

The last statement is proved by applying the "t" test to the mean number of old and new plants with dead or damaged flower buds. The mean number of old plants with dead or damaged flower buds was four per sample while no damaged young plants were observed. Therefore, using the following formula:

$$t = \frac{M_1 - M_2}{s_M} = \frac{4 - 0}{.4421} = 9.05^{**}$$

Greenhouse Studies

Criterion used for measuring the effects of cold on strawberry flower buds in the greenhouse tests was the mean number of flowers produced per plant. The Lot 6 treatment totals are shown in Table 3.

Table 3. Number of normal flowers per plant, Lot 6, both varieties.

Hardened	Treatments: None	24° F	18° F	12° F
None (check)	8.45			
None (check)	7.65			
None		11.14	6.60	
7 days	9.59	8.44	2.00	0.00
14 days		6.61	4.50	

The analysis of variance of the foregoing data is shown in Table 4.

Table 4. Analysis of Variance, Lot 6.

Source of Variation	d.f.	s.s.	m.s.
Between varieties	1	2.01	2.01
Between treatments	11	71.77	6.52**
Variety X treatment	11	10.19	0.93
Totals	23	83.97	

$F_{.01}$ (11,11) = 4.46.

The analysis of variance for the date of Lot 10 is shown in Table 5.

Table 5. Analysis of variance, Lot 10.

Source of variation	d.f.	s.s.	m.s.
Between varieties	2	97.63	48.82**
Check vs treated	1	12.54	12.54
H_0 vs H_{14}	1	10.67	10.67
H_0+H_{14} vs H_7	1	7.35	7.35
Variety X treatment	6	49.61	8.27
Totals	11	177.80	

$F_{.05\,(1,6)} = 5.99$

Further study of the same data yields the following information:

Table 6. Average number of normal flowers per plant for each variety by all treatments and all varieties by each treatment.

Variety	Average number of normal flowers per plant
Blakemore	7.25
Premier	5.44
Treatment	
Check	6.17
H_0	1.83
H_7	5.08
H_{14}	4.50

These data indicate the following information which will be discussed later:

1. The plants seem to reach maximum hardiness in seven days of alternating temperatures of 32° and 56° F.

2. The Blakemore variety was damaged more severely than the Premier variety when both varieties were unhardened.

3. The Premier variety plants hardened fourteen days were damaged more severely than the Blakemore variety plants.

4. Exposure to 12° F damaged flower buds most severely.

5. Plants exposed to 18° F were more severely damaged than plants exposed to 24° F.

6. Plants do not seem to harden in darkness.

7. Due to the high mortality of plants treated at 12° F, it would be difficult to determine if this temperature killed more flower buds than plants.

8. Plants killed by exposure to 18° F seemed to be killed indirectly by damage to the roots and vascular system.

9. Damaged flowers were more prevalent at higher exposure temperatures and less hardening.

10. No varietial difference in damage, blighting, or plant survival could be found.

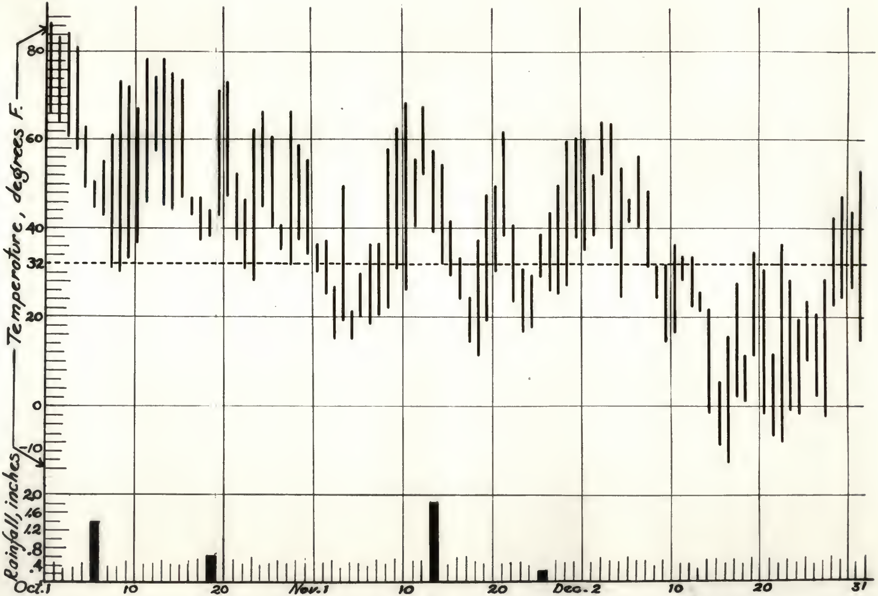


Fig. 1. Weather graph for period Oct. 1 to Dec. 31, 1951.

DISCUSSION

Field Studies

The purpose of the field studies was to determine, if possible, what effect the application of three inches of wheat straw mulch had on the winter survival of flower buds of strawberries.

No differences in the number of plants with dead or damaged flower buds could be detected when comparing the mulched plots against the unmulched check plots.

No difference could be detected in the data, as pointed out previously between the times of application of the mulch. These results could be accounted for by two factors: (1) early winter damage, and (2) the trouble encountered in keeping the mulch on the plants.

The first factor was detected when damaged plants were found in Lot 3 which was collected at the time of the application of mulch on plots mulched November 22, 1951. A study of Fig. 1 shows that growing conditions remained favorable for strawberries until October 29. The growing season was brought to an abrupt end by the cold weather of October 30 and 31 and November 1, 2, and 3. The temperature reached 15° F on November 2, five degrees below the point indicated by Brierley and Landon (1944) as the danger point for strawberries in the field. The lack of hardening temperatures previous to the rapid temperature fall undoubtedly contributed to the damage sustained. This does not agree with the opinion of Darrow (1951) who thought the flower buds entered the winter in a more hardened condition than the rest of the plant. Plate II is a normal undamaged Blakemore flower bud. Plates III, IV, V, and VI show representative types of damage found while sectioning. Plate III shows damaged anthers while the rest of the flower is apparently normal. Plate IV shows another type of differential tissue injury. In this case the receptacle of the primary flower was dead while the anthers and calyx were still alive. "A" points to a normal flower (probably tertiary). "B" points to dead axillary leaf buds found in many cases. Plate V shows the whole flower bud killed while other tissue is uninjured. Plate VI shows a flower bud with injured vascular tissue in the peduncle.

No consistent order of occurrence of damaged tissues appeared. Often flower buds were injured without apparent injury to axillary leaf buds, as well as the reverse condition. In all instances, however, injury to any crown tissue was accompanied by browning of the medulla as mentioned by Angelo (1939) and Colby (1942, 1951). Angelo (1939) stated that some idea of the amount of damage to plants could be determined by the percent of plants with discolored medullae.

The second factor influencing the results of the field study was that of wind blowing off the mulch material. The plots were located on a general south westerly slope, near the top of a ridge, where they were fully exposed to strong southwest winds which repeatedly blew the mulch off the rows, exposing the centers of the rows to the cold temperatures.

The Premier variety sustained a significantly greater amount of damage than the Blakemore variety. This would seem to indicate that the same factors that contribute to the latter variety's plant hardiness, also affect its hardiness of bloom as mentioned by Havis (1938) and the unpublished Kansas data (1951).

This varietial difference could account for the differences in the size of the buds and plants. It was observed that the plants which contained the damaged buds generally were larger than undamaged plants. The dead or damaged buds seemed to be larger and further developed. Hill and Davis (1929) indicate that the process of differentiation continues until halted by frost, the largest and oldest plants start the process first. This might indicate that the buds differentiating at the earliest dates would be larger and further developed, possibly making them more susceptible to damage. A possible varietial difference in time of differentiation might contribute to the varietial hardiness differences.

The data showed that plants over one year old were damaged to a significantly greater extent than those set as runner plants in 1951. This could possibly be explained in two ways. First, as stated above, the time of differentiation could contribute to the hardiness of the young plants. Second, the morphological growth habits of the strawberry plant, as described by White (1927), would place the older crown in a more exposed position. The gradual apical elongation of the stem of the plant would place the crown of the old plants perhaps a half inch or more above the average level of the younger plants away from the heat from the soil.

No blighting of flowers was observed in the bloom period of the field plots. This could possibly be explained in part by the large percentage of plant mortality in those plots during the winter. Those plants that would normally produce blighted inflorescenses, a process that will be explained later, were killed by the comparatively severe winter.

No damaged flower clusters were observed at bloom time. This might be explained by the same conditions as mentioned above.

A large number of non-blooming and non-fruiting plants were observed both at bloom time in the field grown plants and those moved to the greenhouse, giving added support to the above.

Greenhouse Studies

Blighting, as used in this paper, refers to the condition existing when the whole normal inflorescense wilts and finally dies. Plate XI, and Figure 2, Plate XII show typical blighted inflorescenses.

The term "damage" as used in this paper refers to a state of injury to flowers and flower buds of strawberries in which there exists a differential injury or killing of part of the flowers of a bud or infloresconse. The uninjured flowers of such damaged primordia usually develop normally. Figure 1, Plate XII and Plate XIII show damaged blossoms.

Little in the way of a description of experiments of this kind could be found in the literature. A great deal of the methods used were innovations.

A study of the data and Plate VII indicate that the results of Lot 6 were almost a complete reversal of the expected results. It was pointed out previously that some plants of this lot were hardened at 32°-34° F for 7 or 14 days before treatment, without light. Plants hardened the longest periods would be expected to incur the least damage. Such was not the case. Plants hardened longest were damaged most and the unhardened plants were damaged least. After the results became apparent, a recheck of the literature disclosed that Angelo (1939) found that strawberry plants would not harden in darkness. Findings of this study would seem to corroborate this statement.

The data contained in Table 5 clearly indicates that colder temperatures produced a significantly larger amount of damage to flowers. The largest reduction of the mean number of flowers per plant was produced at 12° F. Most of this reduction involved death of the plants. Some badly deformed flowers were produced, and none of the surviving plants treated at this temperature produced a normal number of undamaged flowers.

It has been pointed out previously that 18° F appeared to be the danger point for flower injury. At this point both Lot 6 and Lot 10 showed that flowers and plants may be killed.

Plants treated at 24° F produced damage to some individual flowers only and no blighting. This would seem to indicate that most late spring cold snaps are not responsible for this malady of blighting. Rather, it is probable that temperature, in some part of the winter, produces the damage responsible for later blasting.

Blighting seems to be caused in an indirect way. Plates VIII, IX, and X shows injury to the medulla. In every case of a blighted inflorescense a subsequent sectioning revealed a damaged medulla. In some cases the damage even extended into the pith of the peduncle. Such damage often extended into the vascular system of the crown. This would make it appear that blighting is really a problem of vascular tissue injury. The malady may be caused by enough uninjured vascular tissue remaining after the damage occurred to begin growth and produce normal flowers. Later demands by the young "fruit" and later flowers for moisture and nutrients is in excess of the vascular capacity, producing wilting and later death of the whole inflorescense.

Damage to the flowers was most prevalent at higher temperatures. This damage usually involved the primary and secondary flowers, and occasionally the tertiary flowers. There seemed to be a direct relationship between the size and position of the flower buds at the time of treatment and the amount of damaged flowers per inflorescense.

Damaged flowers were more prevalent than blighting but this difference was not significant. Some damaged flower clusters might have later blighted, but no instance was detected. There appeared to be no varietial differences in either damage and blighting. Other growth habits may contribute to the determination of this type of injury, such as time of bloom, but this was not observed.

With no hardening the data indicate that the Blakemore variety was injured more severely than the Premier variety. This situation was reversed in the 14 day hardening treatments in both Lots 6 and 10. See Plate VII. This would indicate that the earlier blooming Blakemore grew faster and had larger fruit buds before growth was checked by hardening, since all plants were planted at the same time. This would give some weight to the thought that damage often occurs after growth has started in the spring, before the bloom buds have appeared. The 7 day hardening period produced no difference between the two varieties.

Plants seem to reach their maximum hardiness in 7 days as indicated in the analysis of the data of Lot 10. The increased reduction of the mean number of flowers per plant was not significant. Though the mean number of normal flowers produced by the non-hardened plants is small, the difference is not significant.

Though the data discussed here present some evidence of the effect of cold upon the flower primordia, the problem has by no means been solved. More study is needed to discover the physiological and anatomical changes taking place in the plant when it is exposed to cold.

In future studies of this problem the greenhouse trials should be started during the fall. Plants should be exposed to artificial cold temperatures at various stages of development of the flower primordia to find the effects of cold at these various stages. The same process should be repeated in the spring as the plant begins to lose its hardiness and start growth processes.

Another study that appears necessary is the comparative hardiness of old and young plants. Young plants of the various orders of setting from the mother plant probably vary in their cold resistance.

Other factors bearing on the subject that deserve careful study are (1) the effect of diseases such as viruses, (2) soil moisture relationships, and (3) the possible effects of plant growth regulators used in weed control on the hardiness of strawberry flower buds.

It becomes evident from the foregoing discussion and data that strawberry flower primordia are damaged or killed by low temperatures. That the plants may be protected from such injury has been shown previously by Colby (1942), Angelo (1939) and numerous others. This study suggests some of the possible factors involved but by no means solves the whole problem. Future study is of the utmost importance to the strawberry industry in the Mid-west.

SUMMARY

Non-fruitfulness of strawberries following severe winters has long been thought to be due to cold injury to flower primordia. Blighting or "blasting" of strawberry inflorescenses has also been thought to be due to cold injury. Many workers have studied the effects of mulches on yield, and plant mortality, yet no one has ever established cold as a cause of reduced yields.

Experiments were carried out at the Northeast Kansas Experimental Fields near Blair, and in the Horticulture Department greenhouse at Manhattan to study the effects of cold on the flower primordia of strawberries. The effects of cold on other strawberry plant tissues tissues were also studied.

Separate data analyses were run for the field studies and the greenhouse studies.

The field studies indicate the following:

1. Many flower buds were damaged or killed early in the winter when the temperature fell rapidly to as low as 15° F early in November.

2. Flower buds may be killed or damaged in several different ways; (a) complete killing of the whole primordia, (b)

differential killing of the flowers in the bud, (c) killing of the opened flower parts such as anthers, receptacle, or corolla, or (d) injury to part of the vascular tissues of the peduncle, causing later death.

3. No difference in the amount of damage to the flower buds could be found between mulched and unmulched plants.

4. No difference in the amount of damage to the flower buds could be found between the plants in plots mulched at various times through the winter.

5. The lack of difference in the amount of damage between the mulched and unmulched, and the various mulching dates was thought to be due to high winds blowing the mulch off the plants.

6. There was a significant difference between amount of damage incurred by the Premier and the Blakemore varieties. Blakemore proved to be the hardier.

7. There was a highly significant difference in the hardiness of the flower buds of young runner plants set in 1951, and old plants set in 1950, with the young plants being the most hardy.

Greenhouse studies show the following:

1. Plants do not harden in darkness.

2. Plants exposed to 12° F sustained more damage than those exposed to 18° and 24° F. Plant mortality at this temperature largely obscured the direct killing of the flower buds.

3. Plants exposed to 18° F were damaged to a greater extent than plants exposed to 24° F.

4. Eighteen degrees F appear to be the danger point of plant mortality of plants hardened at alternating temperatures of 32° and 56° F.

5. Strawberry flower buds may be killed by cold in two ways; (a) direct killing of the buds, and (b) blighting of the inflorescenses caused indirectly by vascular tissue injury of the plant.

6. Plants of the Blakemore variety appear to lose their hardiness faster than those of the Premier variety.

7. Blakemore plants appear to be capable of greater hardening capacity than Premier.

8. The results of tests with the Sioux variety were too inconclusive to be considered.

9. Plants appear to reach maximum hardiness in 7 days of hardening at alternating temperatures of 32° and 56° F.

10. No definite statistical difference between varieties could be found in the prevalence of flower damage, blighting, and plant mortality.

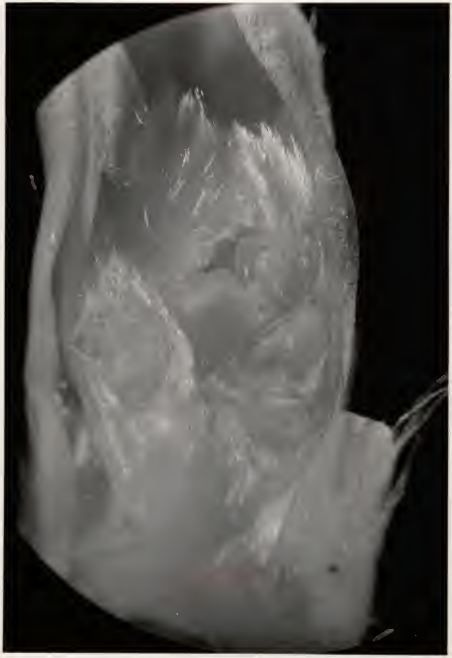
11. Indirect killing of plants may occur as a result of injury to roots or vascular tissue.

More study of several factors contributing to the problem of cold injury to strawberry flower primordia is necessary before many concrete conclusions may be made. Factors to be studied should include such things as soil moisture, the effect of warm mid-winter weather, and means of prevention of wind movement of mulching materials.

EXPLANATION OF PLATE II

PHOTOMICROGRAPH OF A NORMAL FLOWER BUD OF THE BLAKEMORE VARIETY. 76 x.

PLATE II



EXPLANATION OF PLATE III

PHOTOMICROGRAPH OF AN INJURED FLOWER BUD OF THE BLAKEMORE VARIETY. THE ANTHERS SHOW INJURY WHILE THE REST OF THE FLOWER IS APPARENTLY NORMAL. 76 x.

PLATE III

EXPLANATION OF PLATE IV

PHOTOMICROGRAPH OF DAMAGED CROWN OF THE PREMIER VARIETY. LETTER A INDICATES A NORMAL FLOWER. LETTER B INDICATED INJURED AXILLARY LEAF BUDS. 152 x.

PLATE IV

EXPLANATION OF PLATE V

PHOTOMICROGRAPH OF DEAD FLOWER BUDS OF THE PREMIER VARIETY. 76 x.

PLATE V

EXPLANATION OF PLATE VI

PHOTOMICROGRAPH OF FLOWER BUDS OF THE PREMIER VARIETY SHOWING DISCOLORED AREAS, WHICH ARE POSSIBLY INJURED VASCULAR TISSUES. 76 x.

PLATE VI

EXPLANATION OF PLATE VII

FLATS OF THE PREMIER VARIETY THREE DAYS AFTER EXPOSURE TO 18° F FOR FOURTEEN HOURS.

PLATE VII

EXPLANATION OF PLATE VIII

SECTIONED PLANT OF THE PREMIER VARIETY SHOWING INJURY TO THE MEDULLA AND VASCULAR TISSUE. THE PLANTS WERE HARDENED SEVEN DAYS AND EXPOSED TO 12° F FOR FOURTEEN HOURS.

PLATE VIII

EXPLANATION OF PLATE IX

SECTIONED PLANT OF THE PREMIER VARIETY SHOWING DEAD ROOTS AND INJURY TO THE MEDULLA. THE PLANTS WERE NOT HARDENED, AND WERE EXPOSED TO 18° F FOR FOURTEEN HOURS.

PLATE IX

EXPLANATION OF PLATE X

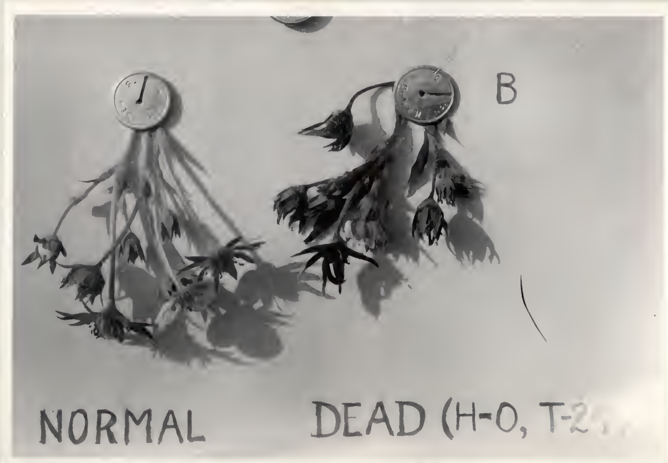
SECTIONED PLANT OF THE BLAKEMORE VARIETY WHICH WAS MOVED TO THE GREENHOUSE FROM THE FIELD SHOWING INJURY TO THE MEDULLA AND VASCULAR TISSUE.

PLATE X

EXPLANATION OF PLATE XI

LEFT, NORMAL FLOWERS OF THE BLACKMORE VARIETY, NOT HARDENED AND EXPOSED TO 24° F FOR FOURTEEN HOURS. RIGHT, BLIGHTED FLOWERS OF THE SAME VARIETY AND TREATMENT.

PLATE XI



EXPLANATION OF PLATE XII

Fig. 1. ENLARGED VIEW OF DAMAGED FLOWERS OF THE BLACKMORE VARIETY.

Fig. 2. TWO INFLORESCENSES ON ONE PLANT OF THE BLAKEMORE VARIETY, THE LEFT HAS BLIGHTED, THE RIGHT IS APPARENTLY NORMAL.

PLATE XII

Fig. 1

Fig. 2

EXPLANATION OF PLATE XIII

CLUSTER OF DAMAGED FLOWERS OF THE BLAKEMORE VARIETY.

PLATE XIII

EXPLANATION OF PLATE XIV

FLATS OF LOT 9 SEVEN DAYS AFTER EXPOSURE TO 18° F FOR FOURTEEN HOURS.

PLATE XIV

EXPLANATION OF PLATE XV

ENLARGED VIEW OF SECTIONED BLAKEMORE PLANT. LINE POINTS TO DEAD FRUIT BUD.

PLATE XV

EXPLANATION OF PLATE XVI

SECTIONED PLANT OF THE BLAKEMORE VARIETY WHICH WAS MOVED TO THE GREENHOUSE FROM THE FIELD SHOWING NEW CROWNS DEVELOPING FROM AXILLARY BUDS.

PLATE XVI

EXPLANATION OF PLATE XVII

SECTIONED PLANT OF THE PREMIER VARIETY SHOWING THE PLANT SENDING OUT NEW ADVENTIVE ROOTS AFTER OLD ROOTS HAD BEEN INJURED.

PLATE XVII

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SOME EFFECTS OF COLD ON THE FLOWER
PRIMORDIA OF STRAWBERRIES

by

JOHN CLAYTON LINGLE

B. S., Southern Illinois University, 1947

AN ABSTRACT OF A THESIS

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PURPOSE

Reduced yields of strawberries following severe winters have long been noticed, but usually have not been associated with low winter temperatures. Many growers have believed that non-fruitfulness has been due, in large part, to late spring frosts killing the blossoms or even the blossom buds before the bloom period.

It was the purpose of this experiment to study the effect of cold upon the flower buds and other plant tissues by field observations and greenhouse experiments. Cultural practices aimed to minimize the effects of cold were also studied.

MATERIALS AND METHODS

Plots of Blakemore and Premier varieties of strawberries replicated at random, were laid out at the Northeast Kansas Experiment Fields near Blair, to study the effect of varying times of application of three inches of wheat straw mulch on the survival of flower buds and plants. Mulches were applied November 22 and December 22, 1951 and February 1, 1952. A fourth plot in each replicate was left unmulched as a check.

Samples of twenty-five plants each were taken at random from each plot at intervals through the winter. Twenty plants of each sample were sectioned longitudinally through the crown of the plant. The sectioned plants were viewed through a binocular dissectiscope to determine the damage to the flower buds. The damaged tissue oxidized rapidly and was easily distinguished. Photomicrographs were taken of representative types of damage. The other five plants of each sample were placed in flats in a greenhouse and were observed closely during flowering and fruiting.

The greenhouse tests included Blakemore, Premier, and Sioux varieties. Twenty randomly selected plants spaced four inches apart were planted in each flat. One flat was used as a replicate for each treatment. The treatments consisted of hardening at 32° F for seven and fourteen days, and exposing to temperatures of 12°, 18° and 24° F for fourteen hours. These were compared with plants not hardened but exposed to the same temperatures. Observations were made of foliage injury, plant survival, and flowers produced. Representative plants were sectioned by the previously explained method.

A second test was run in the same way except that plants were hardened at alternating temperatures of twelve hours each at 32° and 56° F. Illumination of twelve hours per day was provided by means of 200 watt incandescent light bulbs and reflectors. These plants were exposed to 18° for fourteen hours.

RESULTS

Field Studies. Some damage to the flower buds was sustained when temperatures reached as low as 15° F in late October and early November without sufficient cold weather for prior hardening. There were no significant increases in damage in the late mulched and unmulched check plots. Wind blowing the mulch off the plants possibly accounted for the latter results.

This damage was further verified by observations of plants from the same lots which were moved into the greenhouse. Blossom buds which failed to develop into normal flowers were noted, and some plants failed to bloom. Death of the whole plant followed in some cases, apparently as a result of damage to the medulla and roots. The Premier variety was damaged to a significantly greater extent than the Blakemore variety. There was a highly significant difference in old and young plants. Young plants were the most hardy.

Greenhouse Studies. In the greenhouse tests the same types of damage were noted. Plants exposed to 12° F were severely damaged, producing the greatest amount of flower reduction. The critical temperature appears to be 18° F. At this point serious reduction in the number of flowers per plant occurred, and many of the plants were killed. Twenty-four degrees F produced the smallest amount of flower damage, which was produced in a characteristic manner; the receptacles were killed, but the anthers, calyx, and carolla were undamaged.

Blighting was quite prevalent among plants treated at 18° F. This malady is apparently caused indirectly by injury to the vascular tissue of the plant, causing the inflorescenses to wilt and die at a later date.

The Blakemore variety appears to lose its hardiness faster than the Premier variety, but also appears capable of attaining greater hardiness. Neither variety will harden in darkness. Maximum hardiness appears to be reached in seven days under the conditions outlined previously. The results with the Sioux variety were too inconclusive to be considered. No statistical difference between varieties with regard to the prevalence of flower damage, blighting, or plant mortality could be detected.

Concrete conclusions cannot be made until further studies are made of several factors contributing to the problem of cold injury to strawberry flower primordia.