RESPIRATION AND GERMINATION OF IRISH POTATOES IN RELATION TO CHEMICAL TREATMENT AND TEMPERATURE

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By

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INTRODUCTION AND STATEMENT OF PROBLEM

Irish potatoes occupy sixth place in importance of crops grown in Oklahoma, their value being approximately one million and a half dollars in 1935.[1] This is principally the value of the spring crop. The fall crop of Irish potatoes in Oklahoma is rather limited, but constitutes the principal source of the winter supply of potatoes for use in the farm home. Good storage facilities for the spring crop are rarely found on the Oklahoma farm, and under these circumstances, the spring crop is difficult to keep, thus the average farmer usually sells all of his marketable potatoes, using the seconds and culls at times as seed for a fall crop. The fall crop is harvested at a time when the air temperature is low enough to keep the potatoes in common storage.

There are certain problems associated with the use of spring grown potatoes as seed for a fall crop. Spring grown tubers are in a rest period when harvested, and the period intervening between harvesting the spring crop and planting the fall crop is so short, that the dormancy of the spring crop tubers often results in slow and irregular sprouting when they are planted for the fall crop. If the potatoes are planted without chemical treatment, the rate of germination may be so slow as to require so much of the fall growing season that an early fall frost would kill the vines before they had made sufficient growth to produce a crop. Dormancy may be overcome to some extent by the use of chemicals, but the very use of chemicals brings about other problems that must be considered.

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1 United States Census of Agriculture, U.S. Department of Commerce. Vol. 1, p. 715. Oklahoma, 1935.

Other problems associated with the fall production of potatoes in Oklahoma are seed piece decay in relation to high soil temperatures and a limited moisture supply in the soil.

Earlier work at the Oklahoma Agricultural Experiment Station (32) has been done with the use of chemicals to shorten the dormant period of the tubers, to determine the optimum concentrations, and the most agreeable temperature at which spring grown potatoes should be treated. Studies conducted by Kenworthy (21) definitely established the fact that initially, the seed piece "decay" at soil temperatures of 90 to 95°F. is due to an internal physiological breakdown, and not to organisms. This physiological breakdown seemingly arises in relation to high soil temperature, high respiration and a deficiency of oxygen within the potato. The above conditions result in blackhearting of the potato, which injures and disrupts the normal growth process, causing seed piece decay.

At this point there seems to be quite a number of problems relating to fall crop production that have been left unsolved. From these the following have been selected for investigation.

(1) To determine more specifically the maximum temperature at which sprouting of potato sets and tubers occurs, and above which seed piece breakdown may be expected to prevail.

(2) To study the effects of various temperatures and concentrations of ethylene chlorhydrin on respiration in relation to germination and seed piece decay.

(3) To continue the study of seed piece breakdown and to devise, if possible, methods of overcoming this condition.

REVIEW OF LITERATURE

Blackheart

Earlier work at the Oklahoma Agricultural Experiment Station (32) on the problem of a fall crop of potatoes for Oklahoma, has covered many phases, such as the use of chemicals for abbreviating the dormant period, source of seed, and field culture studies. This work was confined largely to field experimentation until 1937 when Kenworthy (21) initiated controlled temperature investigations. Her work consisted of soil temperature studies in relationship to blackheart, treatment with ethylene chlorhydrin, and physiological breakdown of the seed piece. She found that blackheart resulted at high soil temperatures which caused internal breakdown of the potato tissue. She demonstrated that seed piece decay was not caused by pathogenic organisms until after the tissue had undergone a physiological breakdown. Blackhearting of the tuber always preceded death at high temperatures.

Other investigators have produced blackheart under various conditions, Stewart and Mix (39) found that with a volume of air equal to the volume of potatoes, a period of ten to twelve days resulted in blackheart, provided the temperature was maintained around 70°F. At temperatures of 50° to 60° they reported about twenty days were required, and at 40° a still longer time was required, ranging from twenty-three to forty days. Bartholomew (6) in 1915 indicated that the accumulation of carbon dioxide, or the products of respiration, and the lack of oxygen brought about the death of the cells. Under laboratory conditions he was able to produce blackheart at 101 to 111° in from fifteen to twenty-four hours.

In India Mann and Joshi (27) found that tubers in open wire baskets at ordinary temperatures of 72 to 86° F. remained sound for indefinite periods of time, when at 97° under the same conditions of aeration, blackheart occurred in about six days. When tubers were placed in sealed containers in which air was replaced by carbon dioxide or nitrogen, or when tubers were coated with collodion or paraffin, blackheart occurred in six to twelve days at 81 to 86° F.

Bennett and Bartholomew (7) found blackheart to appear usually in 6 to 12 days at temperatures of 95 to 104°.

Appleman (2) conducted studies on the accumulation of carbon dioxide in the soil with late crop potatoes. He found that the accumulation delayed growth, but did not entirely prevent sprouting of the tubers. His experimentation was carried out in Maryland where the soil temperatures are probably not quite as high as those in Oklahoma.

Davis (11) produced blackheart in potatoes under laboratory conditions at a temperature of 113° in a carbon dioxide-free atmosphere in which there was an abundance of oxygen available. He found that during the time preceding the incidence of blackheart, carbon dioxide accumulates rapidly in the internal atmosphere of the tuber, and oxygen is rapidly depleted until the inter-cellular gasses contain more than 50% carbon dioxide and less than 4% oxygen; and that this condition is followed by increasing permeability of the protoplasm together with certain other changes. His conclusions were that blackheart apparently was the result of high respiration and the failure of the gas exchange to keep pace with the respiration rate. This assumption agrees with that of Bartholomew (6).

Kidd (22) found that when the composition of internal gases reached more than 20% of carbon dioxide, the potato was injured, and serious injury occurred at 30% accumulation. Magness (25) reported finding composition of gases in the inter-celluar spaces of potato tissue at 86° F. to be more than 34% carbon dioxide, while the amount of oxygen was less than 5%.

Singh and Mathur (36) showed a definite negative correlation between the occurrence of polyphenol oxidase and diastase and the degree of incidence of blackheart of potatoes. They attributed this to the partial destruction of polyphenol oxidase and diastase due to the excessive heating of the enzymes.

Dormancy

"Dormancy" and "rest period" are terms which will be used interchangeably to indicate that period during the normal life of the potato in which sprouting will not take place, even though external conditions are favorable.

The relation of dormancy to the per cent germination of the potatoes used as seed in fall crops has been investigated widely at different experiment stations, but apparently to the writer's knowledge none of these stations has studied the relationship of high soil temperatures to chemical treatment and respiration of the tubers. In the present study the effects of chemical treatment and high soil temperature are being considered.

The duration of the period of dormancy of potato tubers depends on several factors, some of which are:

(1) Tuber maturity at harvest time.

(2) Temperature and humidity of the storage room.

(3) Periderm thickening

(4) Oxygen supply

(5) Varietal characteristics

It should be noted that the first four factors relate to periderm thickening and permeability.

Appleman (3) suggested that the continuance of dormancy is largely due to a lack of oxygen in the internal tissue. He has shown that when the periderm was removed thus admitting oxygen, or when oxygen was introduced by other means, sprouting of the dormant tubers was hastened. He concluded that dormancy may be broken by any method which increased the rate of respiration.

Miller (30) experimented with various chemicals in relation to growth releasal and the respiration rate of potatoes. He found that certain chemicals such as primary alcohols, reduced the respiration rate, yet others such as urea and acetamide, could break the dormancy without either decreasing or increasing the respiration rate. However, the majority of the chemicals did increase the respiration rate, and at the same time, broke the dormancy.

Kidd (22) came to the conclusion that for germination of the potato, the optimum concentration of oxygen in the internal gases should be eight to twelve per cent.

Werner (43) working with dormant tubers, states that no definite interval of time can be named as the length of the dormant period, but that the duration of the period will depend upon various factors such as tuber maturity at harvest time, and temperature and humidity of the storage room. He found that emergence from the dormant period is a gradual transition and not an abruptly occurring incident.

Rosa (35) found that dormancy was related to tuber maturity, for in a series of twelve tests the average number of days required for the sprouts to emerge was greatest in tubers harvested earliest, and decreased regularly as the time of harvesting was extended; and the time required for germination was shortest in the samples harvested when the tubers were most mature. He further showed that emergence from the rest period is not abrupt, and that some time in storage is required to secure prompt and uniform sprouting.

Denny and Miller (13) found that chemical treatment was less effective in breaking the dormancy of the potato as the tuber approached the end of its rest period, and that this was due to a decrease in the amount of ethylene chlorhydrin absorbed in association with the natural thickening of the periderm of the potato.

Several investigators have found that storage at low temperature is a mild dormancy-breaking treatment. Wright (44) attributed this dormancy-breaking treatment to the accumulation of carbon dioxide in the potato tissue while stored at 33°. He also pointed out that potatoes removed from 33° storage and placed at 95° respired far more than potatoes taken from 70° storage and placed at 95°. Muller-Thurgau (31) and Werner (43) found that low temperature storage of tubers is a mild dormancy-breaking treatment.

Loomis (24) found that storage at 95° was a dormancy-breaking treatment, and that planting potato sets in soils at 95° further aided in producing rapid germination of dormant tubers.

Rosa (35) found that periderm formation was related to the dormancy of potato tubers. In his studies he cut tubers and stored the sets at different temperatures (10 to 25° C.) for 28 days before planting in order to allow wound periderm formation to take place in an attempt to prevent rotting. Poor germination from these suberized sets was believed by him to be due to a secondary dormancy induced by the periderm formed. In the light of our present knowledge, this result was explained on the basis of oxygen absorption (Kenworthy (21).

Artschwager (5) found that freshly harvested tubers or wounded tubers formed a very shallow periderm when subject to high humidity, but when placed in an atmosphere having a low humidity, a thicker or heavier periderm was formed.

This closely relates to the work of Smith (37), Appleman (3), and Rosa (35), who found that tubers stored in moist conditions, or tubers subjected to high humidity or stored in contact with some material holding moisture, such as peat moss, had a shorter period of dormancy than tubers stored in a dry atmosphere. Smith concluded that moist storage delayed suberization which facilitated the exchange of gases and encouraged the sprouting activity. Appleman (3) believed that delayed suberization favored a rapid gas exchange which allowed greater absorption of oxygen, thereby causing a breaking of the dormancy.

As mentioned before, Miller and Denny (29) showed that dormancy was broken more readily by chemical treatments with tubers having a thin periderm than with those having a heavy periderm.

Treatment with Ethylene Chlorhydrin to Break Dormancy

Denny (12) found that it was important in treating potatoes with ethylene chlorhydrin to avoid treating at temperatures higher than 85°. This work was confirmed by Kenworthy (21) who found that if the temperature was above 85° during and immediately following the twenty-four hour treatment, blackheart would result. She also found that the concentration of ethylene chlorhydrin necessary to break dormancy was low, and that concentrations of more than 1 cubic centimeter of 40 per cent commercial ethylene chlorhydrin per liter of air space in vapor treatment were always injurious.

According to Denny and Miller (13), freshly harvested tubers take up much larger quantities of ethylene chlorhydrin when treated under the same conditions than tubers from the same lot at a later date. Miller and Denny (29) in a later experiment found that the partial removal of the periderm resulted in the absorption of more ethylene chlorhydrin by the tubers. This indicates that periderm formation of the tubers is an important consideration in standardizing any treatment with the above chemical.

Miller and Denny (29) also found the amount of ethylene chlorhydrin required to induce sprouting in the tuber to be exceedingly low, ranging from 1 cubic centimeter of 0.1 Molar ethylene chlorhydrin per 100 grams of expressed juice, to 15 centimeters. They reported that the rate of sprout emergence increased with the increase of ethylene chlorhydrin found in the tissue, but that a concentration of more than 15 cc. increased the amount of seed piece decay.

Smith (37) found that treating with ethylene chlorhydrin increased the rate of respiration, and the stronger the treatment within the range of concentrations used, the higher the rate of respiration.

It is significant that the use of increased concentrations of ethylene chlorhydrin results in higher respiration rates and usually the occurrence of more decay.

Respiration

Since Davis (11) and Bartholomew (6) had related blackhearting to the rate of respiration and the resultant by-products, and Appleman (3) had said that increasing the rate of respiration would cause a shortening of the rest period, it was logical that the literature relating to carbon dioxide concentration and rate of respiration should be considered.

Van'T Hoff's law (40) states that for every ten degree (Centigrade) rise (over a range from 0 to 30° C.), the rate of most physiological processes is doubled or tripled. The process of respiration has been shown by Gore (15) to conform to this rule, who found that the rate of respiration increased from 1.89 to 3.01 times and averaged 2.376 for each ten degree rise in temperature, in connection with his studies with fruit.

Kimbrough (23), experimenting with the storage of potatoes, found that the increased respiration rate of potatoes moved from a low storage temperature to a high temperature could not be attributed to the accumulation of carbon dioxide in the potato tissues at the low temperature. His calculations show that the potato tissue cannot absorb and hold as much carbon dioxide at the low temperature as would be given off after the potatoes are moved to a higher temperature. He also found that the respiration rate, determined at various constant temperatures, varied with the temperature at which respiration was tested, the higher temperature causing a higher respiration rate. Whether the decrease in the respiration rate of harvested potatoes declined due to maturity or to increased thickening of the periderm, none of the investigators said. Smith (37) and Rosa (35) found that potato tubers have a high respiration rate immediately after digging which gradually declines as the potatoes attain maturity in storage.

Magness (25) found an accumulation of carbon dioxide as high as 34 per cent in potatoes that had been subjected to a temperature of 30° C.

Contrary to Van'T Hoff's law (40), Hopkins (19) observed an increasing rate of respiration at low temperatures of 3 to 0° C., which he attributed to the accumulation of reducing sugars. He further found that respiration is more closely correlated with the amount of reducing sugars present than temperature until the amount of reducing sugars collected begins to inhibit respiration, at which time the temperature is a greater factor than the sugars.

Appleman and Smith (4), experimenting with potatoes found that at 0° to 30.0° C. there was no correlation between reducing sugars and the rate of respiration.

Palladin (33) suggests that respiration rates are greatly stimulated by temperature changes from low to high. Kimbrough (23) found that a period of four weeks in cold storage was necessary to cause the maximum difference in the respiration rate over tubers kept constantly at the higher temperatures. He demonstrated that this stimulated respiration on removal is not due to carbon dioxide accumulation in the potato tissue during the storage at low temperatures. Wright (44) found that this four week's exposure to low temperature allowed for a maximum amount of carbon dioxide to be accumulated in the tissue.

Magness (25) believes that the exchange of gases in respiration is more easily facilitated at the higher temperature, since he cites Denny (12), who indicated that the tissue is more permeable at higher temperatures to water, and thus, Magness assumes that the same tissue would be more permeable to the various gases. Smith (37) found that the internal tissue and periderm of the potato had a very low degree of permeability to carbon dioxide.

Magness and Diehl (26) investigating paraffin coated and uncoated apples in storage for the composition of internal gases, found that the coated potatoes had a reduced rate of respiration; but that carbon dioxide accumulated in the tissue, and at high temperatures internal browning of the apple tissue occurred.

According to Smith (37), treating potatoes with ethylene chlorhydrin resulted in a higher concentration of carbon dioxide in the tissue and breaking of the dormancy, but treating with carbon dioxide alone did not break dormancy though carbon dioxide accumulated in the tissue.

Appleman (2) came to the conclusion that a concentration of carbon dioxide in the soil atmosphere of 5 per cent would not retard the rate of germination sufficiently to cause seed piece decay.

Through the association of the work of Davis (11), Bartholomew (6), Magness (25), and Smith (37), it is conceivable that with high temperature, high respiration rate and the accumulation of carbon dioxide in the potato tissue, blackhearting and physiological breakdown may occur. Whether this is due to the by-products of respiration (carbon dioxide) as indicated by Singh and Mathur (36) and Davis (11) or whether it is direct injury by carbon dioxide as shown by Kidd (22), is not known; but that injury does occur is beyond doubt. That it is as much the lack of oxygen and impermeability of the intact periderm, or suberized periderm to gas exchange with the depressed rate of respiration seems most likely.

Wounding

In connection with respiration it would seem logical that cutting the tuber would give a more permeable surface and thus the rate of respiration could be increased by the set without much injury when planted in the field under high temperatures.

Palladin (33) found that the rate of respiration following wounding increased until the twenty-eighth hour, then it began to decline, and he indicated that approximately 93 per cent of this increase was due to the mechanical facilitation of gaseous exchange, and not to the wound stimulation caused by actual cutting as was thought by Appleman (3) when he stated that wounding was a mild dormancy-breaking treatment. Johnstone (20) found that wounding of sweet potato roots mechanically facilitates respiration, and the increased rate of gas exchange due to wounding was not a direct wound stimulus.

Loomis (24) and Werner (43) found that one ounce seed pieces from large potatoes of 4-ounce size germinated better than small, whole potatoes of the same size. Loomis attributed this to the large potatoes coming out of their rest period more rapidly. In the light of the present work and the work of Rosa (35) and Smith (37), the writer feels that better germination of cut sets is due to ease of gas exchange through the large cut area which is readily permeable to gas exchange; whereas, the small, whole potato has an unbroken periderm which retards the absorption of oxygen and the release of carbon dioxide.

Soil Temperatures

It is generally accepted that high soil temperatures induce seed piece decay. Bushnell (8) stated that it is inadvisable to plant fall-crop potatoes in Ohio while the soil temperature is high. Vincent and Pawson (42) found that the per cent of germination at temperatures above 70° depends on the soundness of the tubers; that less decay results from tubers sprouted before planting; and that excessive moisture in the soil at a temperature of 57° was found to induce seed piece decay. Loomis (24) indicates that excessive seed piece decay will be found at temperature of 95°, though the potatoes may sprout more quickly following storage at the same temperature. He concludes that the loss through seed piece decay at 95° is so high that yields would be unprofitable.

METHODS AND MATERIALS

(All temperatures, unless otherwise noted, are expressed in degrees Fahrenheit)

Germination Studies:

Throughout these experiments the potatoes were germinated in ordinary greenhouse flats that measured 14" x 22" x 4". A mixture of one-half building sand (30 mesh) and one-half German peat was used as a germination media. This resulted in a mixture that has some of the physical properties of soil, yet would be easier to handle, and could be used repeatedly. The flats were filled with a half-inch layer of this mixture. The sets were placed on this and then covered with sand and peat to a depth of about two inches. Emergence is the term used to designate when the sprout showed above the media.

The flats were then placed in constant temperature cabinets at 70°, 90°, and 95°, depending upon the design of the experiment. Seventy degrees was selected as being near the optimum for the germination of the sets and tubers. To attain this temperature, a cabinet having a cooling unit was used.

Each cabinet was equipped with a 450 watt hot plate, an electric fan, and a shallow pan 20" in diameter. The fan and hot plate were operated in connection with a Dekotinsky thermostat.

The air stream from the fan was directed over a free water surface in the pan and over and around the hot plate to provide a moist atmosphere with a uniform temperature throughout the cabinet. The temperature was constant on any one of the four shelves, but varied slightly from shelf to shelf.

The cabinets measured 3' x 3' x 7'. Each had four shelves, each shelf accommodating two flats, making a total of an eight-flat capacity for each. The cabinets were constructed of "Celotex" with double wall insulation.

Respiration Apparatus and Determinations

In order to determine the effect of temperature and chemical treatment on potato tubers, respiration apparatus was devised. The apparatus was a modification of that used by Harding, Maney and Plague (16(17), with the use of a Reseit Tower as modified by Truog (41). See Fig. 1.

In order to remove the carbon dioxide from the air, two flasks of sodium hydroxide solution were used in the first two experiments on respiration, with a flask of barium hydroxide solution to check the efficiency of the sodium hydroxide wash. During the 39 days of the first two series, there was no perceptible precipatate formed in the barium hydroxide solution, but the moisture drawn in with the air from the wash bottles accumulated in the respiration chambers. In the last series the barium hydroxide solution was replaced by a third flask of sodium hydroxide. A soda lime U-tube was inserted after the last flask in order to remove the moisture from the air.

From the Reseit tower the air passed through pipes to a fifty gallon steel drum that was used to provide a vacuum reserve. The air was drawn from the drum by a small vacuum pump that was operated by a motor controlled by a relay and mercury switch, which in turn was operated by the vacuum pressure in the drum. Note Fig. 2

The rate of air flow in the towers was adjusted to what was

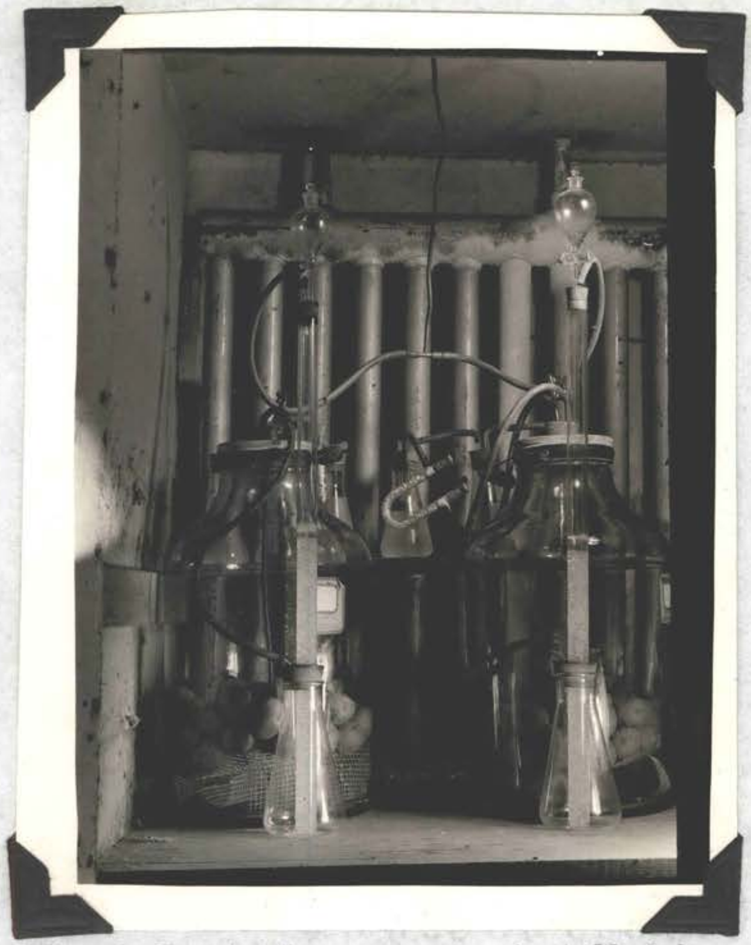

Fig. 1 Respiration apparatus installed in constant temperature chamber.

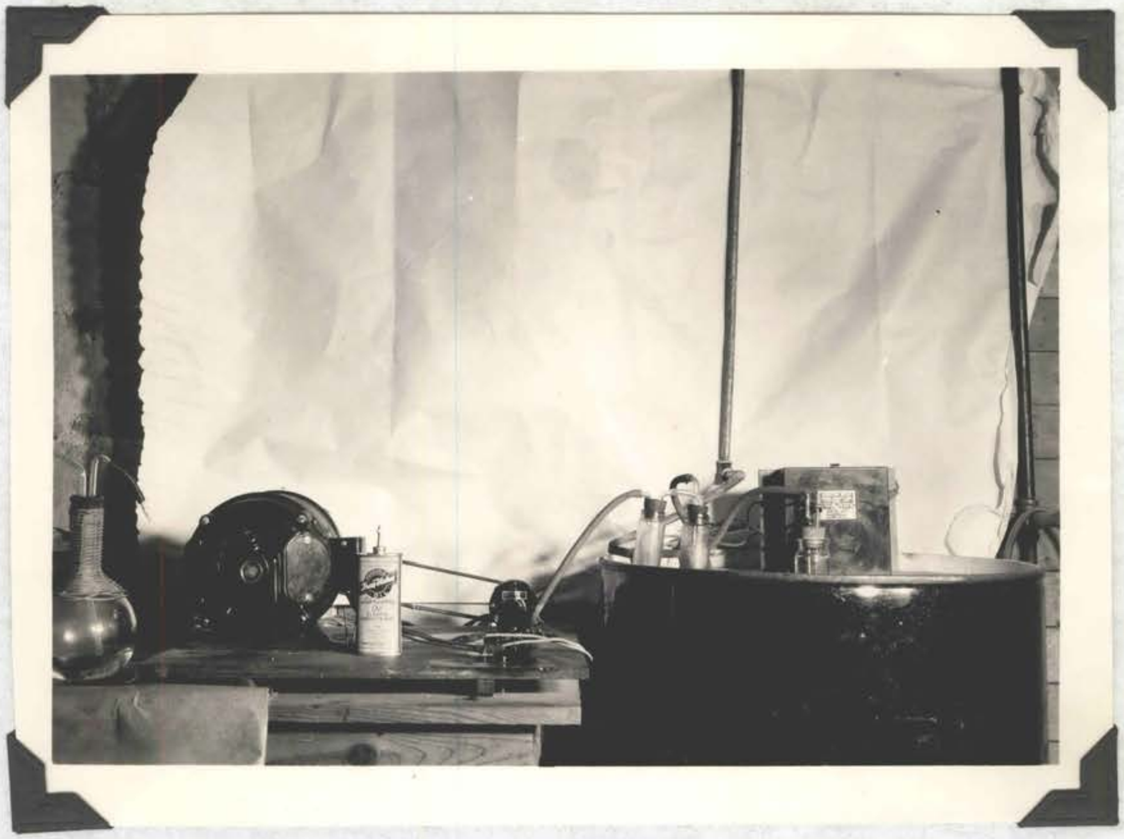

Fig. 2 Vacuum pump, vacuum reserve
and controls

judged to be a constant removal of the carbon dioxide that was evolved from the tubers.

The carbon dioxide respired by the potatoes was absorbed in approximately 2 N potassium hydroxide. A double titration of phelolpthalein and methyl orange was used to determine the amount of carbon dioxide which was absorbed by the solution of alkali in a twenty-four hour period.

The alkali and glass beads were washed from the Reseit tower into the flask and the titration carried out. A motor-driven stirring device was arranged to fit into the flasks in order that the solution could be thoroughly mixed during the titration.

The results of the titrations were expressed in terms of milligrams of carbon dioxide respired per kilogram hour. Approximately 2 N sulfuric acid was used to titrate the potassium hydroxide.

The milligrams of carbon dioxide per kilogram hour was determined, and used to express the amount of carbon dioxide evolved. The formula below was used for this calculation.

$$\frac{\text{Phen. reading} - \text{Methyl orange reading} \times \text{carbon dioxide equivalent}}{\text{No. of kilograms of potatoes} \times \text{Hours of test}}$$

Analysis of variance was used to determine the significance of the results for various treatments and temperatures. Snedecor's Table of F Values (38) was used to determine the one percent and five percent levels of significance.

<u>Treating Potatoes with Ethylene Chlorhydrin</u>

Samples of about 2500 grams of tubers were treated in five gallon wide-mouth pickle jars, and the potatoes allowed to stand for twenty-four hours at a temperature of 75 to 80 degrees. At the end of this period the tubers were removed from the jar and allowed to remain in the open for another twenty-four hour period before being installed in the respiratory apparatus. In Experiment VI the potatoes were placed in a 40 liter can and 20 cubic centimeters of ethylene chlorhydrin were used in the treatment.

The ethylene chlorhydrin was absorbed by a piece of cheese cloth which was spread over a screen cone. This cone was set in a large watch glass which was placed over the tubers in the can. The ethylene chlorhydrin solution used in the treatment was the commercial 40 percent solution, 1 cubic centimeter of which is equivalent to approximately 50 cubic centimeters of 0.1 molar ethylene chlorhydrin.

The concentrations of ethylene chlorhydrin used in Series I and II of the respiration experiments was 0.5 and 1.0 cubic centimeters per liter of air space, respectively. In all studies untreated tubers were used in comparison with the treated ones.

<u>Determination of the Ethylene Chlorhydrin Absorption</u>

The method used by Denny and Miller (13) was followed in determining the amount of ethylene chlorhydrin absorbed during the treatments. The determinations were made on the juice extracted from the potatoes rather than directly on the tissue. The method is based on the fact that ethylene chlorhydrin forms a constant boiling mixture with water, and can, therefore, be quantitively recovered by distillation.

A representative sample was taken from each lot of treated potatoes. The tubers were washed in distilled water to remove any possible chlorides from the surface, and then dried. The potatoes were quartered and ground through a food chopper. The ground tissue was placed in a cheese cloth and the juice pressed out by hand. This juice was freed of starch by decantation, after which it was distilled and the distillate was collected in a 250 cc. volumetric flask containing 9 grams of barium hydroxide.

After the distillate had stood for twenty-four hours, an aliquot was analyzed for chlorine by the Volhard (40) method.

Since the solution contained barium hydroxide, the recommended ferric alum indicator could not be used because it gave a white precipitate that caused a confusion of the end point when titrating with potassium thiocyanate; and, therefore, ferric nitrate was substituted which gave a very sharp end point without forming a precipitate with the barium hydroxide.

The amount of chlorine found is expressed in cubic centimeters of 0.1 molar ethylene chlorhydrin per 100 cc. of the original sample of juice.

EXPERIMENT I

RELATION OF TEMPERATURE AND PRESENCE OF SPROUTS TO EMERGENCE AND SEED PIECE DECAY

Soil temperatures frequently reach 90 to 95 degrees and above, during or shortly following the time of planting potatoes for the fall crop in Oklahoma. In 1938 the soil was cool during this period because of frequent rains, yet the mean temperature from July 25 to August 7, 1938 was 89.4° with a maximum of 102° on August 6. See Table I.

Such high temperatures have been found to produce blackheart (Bartholomew (6), which would thus result in seed piece decay. Macmillan and Meckstroth (28) found that sprouting had a preservative effect on the seed piece. With these two facts in mind, the writer thought perhaps sprouting would preserve the seed piece even at the above temperatures, until the set had established a plant.

The first objective in this experiment was to determine the maximum temperature at which sprout emergence would be possible, and to investigate the possibility of the protective action of the sprout. These investigations involved the following set-up. Half the tubers were placed at 95° and the other half at 70°.

Series A

Variety	Treatment	No. of Sets	Ave. Wt. (Oz.)	Ave. Sprout Length
Houma:	Sprouted Cut	60	1.5	1.8 mm.
	Sprouted Whole	60	1.0	1.6
Bliss Triumph:	Sprouted Cut	80	1.0	1.5
	Sprouted Whole	80	1.5	1.7
	Not Sprouted Cut	80	1.0	
	Not Sprouted Whole	80	1.5	

TABLE I

Soil and Air Temperatures, July 25-August 7, 1938

Date		Mean Air Temperature	Maximum Soil Temperature	Mean Soil Temperature
July	25	79.21°F.	90°F.	88°F.
	26	78.5	90	89
	27	84.17	91	90
	28	78.94	97	83
	29	75.2	84	80
	30	78.28	86	82
	31	78.5	86	84
Aug.	1	78.27	92	87
	2	85.0	94	90
	3	84.0	95	91
	4	84.5	92	90
	5	83.5	100	91
	6	86.0	102	94
	7	86.0	96	92

Mean Soil temperature for the two-week period = 89.4°F.

These treatments were started on October 25, 1938 and by October 29 all those in the 95° temperature showed blackheart involving as much as one-third of the potato. By the ninth day, all of the 95° treatments were removed because the potatoes had rotted except those of the variety Houma, which showed some resistance to decay. See Fig. 3.

From these results it seemed apparent that the next step would be to select the intermediate temperature of 90° to determine the point above which the percent of seed piece decay would be so large as to prevent 50 percent emergence. Series B was then set up as follows with half the tubers placed to germinate at 70° and the other half at 90°.

SERIES B

Variety	Treatment	No. of Sets	Ave. Wt. (Oz.)	Ave. Sprout Length
Warba:	Sprouted Cut	30	1.2	1.9 mm.
	Sprouted Whole	30	2.3	1.7
Bliss Triumph:	Not Sprouted Cut	40	1.4	
	Not Sprouted Whole	40	1.4	
	Sprouted Cut	40	1.4	1.4 mm.
	Sprouted Whole	40	1.4	1.6

This series was started on November 3, 1938, and continued for twenty-one days.

Table II shows the results of Series A and B, Experiment I. It should be noted from this table that there is a considerable difference in the percent of sound potatoes that had been sprouted before planting as compared to those that had not been sprouted. Notes taken on the potatoes placed at 95° show that the preservative effect is nearest the sprout (See Fig. 4), indicating that the sprout is associated with some preservative effect on the tuber. On digging into the soil

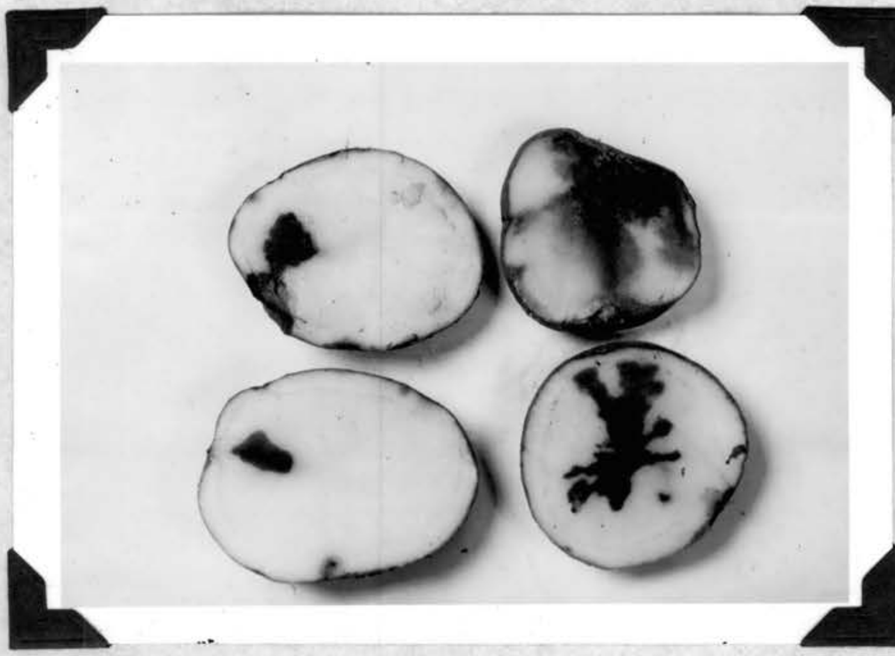

Fig. 3
Blackheart found on fourth day of Experiment I,
Series A

TABLE II GERMINATION RESPONSE OF SPROUTED AND UNSPROUTED, CUT AND WHOLE POTATOES, AND VARIETIES AT HIGH AND OPTIMUM TEMPERATURES.
(Results of Experiment I, Series A and B)

Variety	HOUMA		T R I U M P H								W A R B A			
Temperature (Degrees F.)	70		70				90				70		90	
	Sp. Cut	Sp. Whole	Cut Sets		Whole Sets		Cut Sets		Whole Sets		Cut	Whole	Cut	Whole
Data Secured (%)			Sp.	Unsp.	Sp.	Unsp.	Sp.	Unsp.	Sp.	Unsp.	Sp.	Sp.	Sp.	Sp.
Sound	96.6	100	77.5	62.5	80.0	87.5	2.5	5.0	95.0	15.0	20.0	50.0	13.3	10.0
Rotted	3.3	---	22.5	37.5	20.0	12.5	97.5	95.0	5.0	85.0	80.0	50.0	86.3	90.0
Sets emerged**	100.0	100	85.0	75.0	92.5	90.0	40.0	15.0	100.0	32.5	33.3	100.0	76.6	50.0
Sound, not emerged	----	---	----	----	----	----	----	----	-----	----	----	-----	----	----
Rotted, emerged	3.3	---	15.0	12.5	7.5	2.5	37.5	10.0	5.0	17.5	13.0	50.0	63.6	40.0
Rotted, not emerged	----	---	7.5	2.5	12.5	10.0	60.5	85.0	-----	92.5	66.6	----	23.3	60.0
No. Sprouted tubers	30	30	34	30	37	36	16	6	40	13	10	30	23	13
Ave.Wt.of Sprouts/tuber*	17.3	6.9	14.6	17.3	17.2	8.7	14.2	7.5	8.5	10.7	15.9	11.3	7.5	6.4
Days for 50% emergence	4	6	6	9	9	12	18	18	18	21	9	12	18	18

** Emergence of sprouts above surface of media.
* Grams
Sp. stands for sprouted
Unsp. stands for unsprouted

Note: Maximum germination was obtained on the 21st day of each experiment. A duplicate test was set up at 95°F. but no data was secured because all tubers and sets showed blackheart within four days and all rotted within nine days.

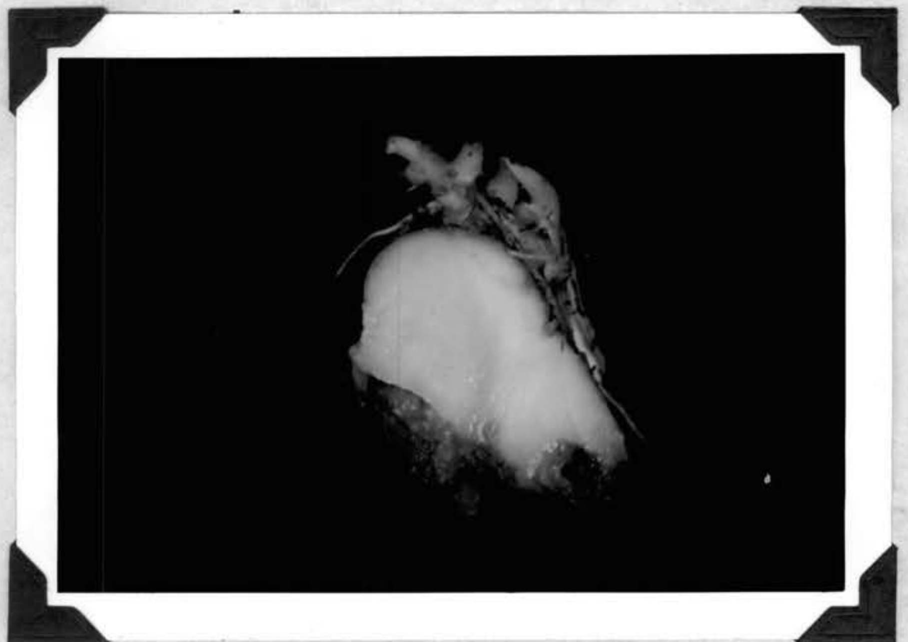

Fig. 4 Sprouted tuber placed at 95°. Rot beginning in tissue farthest away from sprout. Note lateral branches on sprouts.

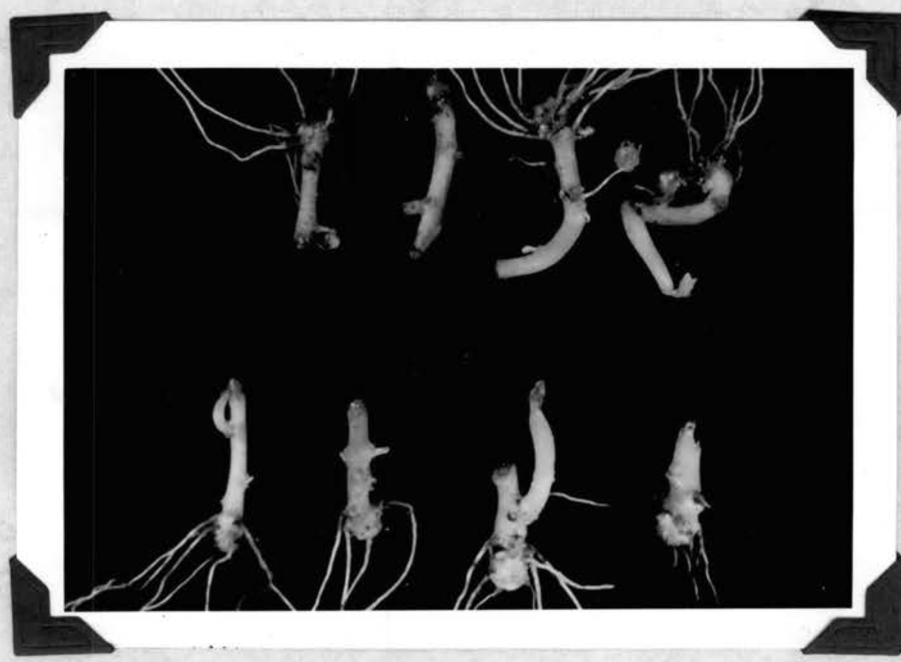

Fig. 5 Tubers placed at 95°. Sprouts growing upward and dying. Lateral branches of sprouts beginning to grow below the dead tissue.

of the flats placed at 95°, many small sprouts were observed to have grown up to the top of the soil, at which point the tips died and new lateral sprouts had started below the dead tissue. These had also died back. (See Fig. 5)

The above results indicate that the rotting of the seed piece may be so rapid that the sprout attached thereto may lose its source of food supply before it can become established.

It appears that the meristematic tissue of the growing points is more readily injured by heat than the more mature tissue in the other parts of the shoot. This same condition had previously been noted by Cordner (10) in the experimental field at the Oklahoma Experiment Station farm. While taking the emergence count on the fall crop of potatoes during the last week in August, 1938 (the soil temperature had been steadily rising until it stood at 98°), he had observed that the count showed less emergence instead of more. Digging into the soil, he found sprouts near the top of the soil, the growing tips of which were brown and showing signs of decay. Later, new lateral sprouts started and continued to grow and establish plants. (See Fig. 6).

In the constant temperature cabinets in the 95° section, many tubers were entirely decayed, but those sprouts remained alive that had been started on the tuber before it was placed in the cabinet. The basal end of these was calloused over and root development was limited (Note Fig. 7). It seems, then, that the establishment of the plant depends on the rate at which the tubers or sets are consumed by the process of decay. Even though the sprout may establish a plant after the seed piece has decayed, the plant may be weakened and probably would not have sufficient time to mature tubers for the fall

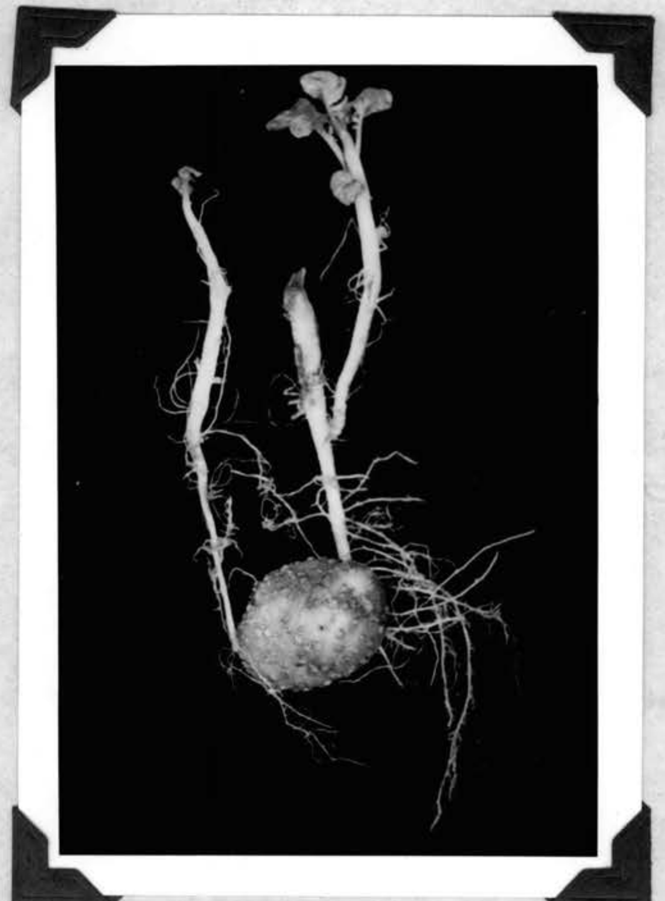

Fig. 6. Tuber planted in experimental field. Growing tip of sprout showing signs of decay; lateral sprouts established and growing.

Fig. 7. Basal ends of sprouts calloused over with limited root development.

crop before being killed by frost.

It was found in both Series A and B that sprouted whole potatoes had less decay than tubers of other treatments at a temperature of 90°. The percentage of decay at 90° was less when both cut and whole sets were sprouted before planting. The number of 50% emergence was least on the sprouted potatoes, and the sprouted potatoes made better growth, as is indicated by the greater weight of emerged sprouts as compared with the weight of the emerged sprouts of the tubers that were planted unsprouted. It was found that whole, unsprouted sets showed better results than cut, unsprouted sets. This was contrary to results found by Kenworthy (21) who reported that cut, unsprouted sets did better than whole, unsprouted sets. However, in later experiments the writer's data agreed with Kenworthy's.

It was found that seed piece decay decreased with the decreasing number of days required for 50% emergence.

In summarizing the results of Series A and B, it may be said that sprouting carries sufficient preservative effect upon the set or tuber to establish the plant even under high temperature conditions, provided that the period of high temperature is not too long. It seems probable that the preservative effect is associated with the aeration of the tuber by the sprout, together with what might possibly be some hormone manufactured in the sprout, as suggested by Mann[2] who stated:

> "My own impression, though I have not had any proof, has been that the reduced susceptibility of potatoes to rot at high temperatures when they are sprouting or getting ready to sprout is due to the definite production of substances or enzymes (hormones?) as soon as the potato begins to grow."

---

[2]Mann, H.H. Woburn Experiment Station, Aspley Guise, England. Personal Correspondence.

At 95° it would be unlikely for the sprout to emerge and establish a plant, but at 90° it is possible for the plant to survive.

SERIES C - EXPERIMENT I

Series A and B indicated that sprouted whole potatoes were more desirable for planting at high temperatures than any other types of seed pieces studied. In order to more definitely determine the difference between sprouted whole and unsprouted whole potatoes, the experiment was designed as follows, with one-third of the tubers of each treatment being placed at 70°, 90°, and 95°.

Variety	Treatment	No. of Sets	Ave. Wt. of Sets(oz.)	Ave. Sprout Length
Warba:	Not Sprouted	90	2.4	
	Sprouted	90	2.4	1.8 mm.
Bliss Triumph:				
	Not Sprouted	108	1.5	
	Sprouted	108	1.6	1.5 mm.

Table III contains the complete results of Series C. It should be noted that the variety Warba did not emerge from the soil at either 90° or 95°.

The variety Triumph did not make normal emergence at the 70° temperature. More potatoes of this variety remained sound at 90° than at 95° . The sprouts from sets planted at 90° emerged from the soil in a normal condition, while those at 95° emerged with blackened tips and put out new laterals, as was found in Series A and B. It was found that at 95° the same percent of sound tubers of the sprouted and not sprouted treatments were left when the experiment was concluded, but the potatoes that were not sprouted before placing in the

TABLE III - EFFECT OF TEMPERATURE ON VARIETIES AND SPROUTED AND UNSPROUTED POTATO SETS
(Results of Experiment I, Series C)

Variety and Treatment	Temperature (Degrees F.) 70			90			95		
	% Rotted	% Sound	% Emerged	% Rotted	% Sound	% Emerged	% Rotted	% Sound	% Emerged
Triumph:									
Sprouted	87	13	63	31	69	84	93	7	60
Unsprouted	90	10	17	47	53	60	93	7	20
*Warba:									
Sprouted	50	50	--	--	--	--	--	--	--
Unsprouted	67	33	--	--	--	--	--	--	--

*Note: Warba in 90° and 95° temperatures showed complete rot with no signs of sprouting.

cabinets had made only 20% emergence in comparison with 60% for the previously sprouted potatoes.

This has definitely shown that sprouting previous to planting will enable the tubers to establish plants, while the unsprouted set breaks down and decays before sprouting begins, or is so late in sprouting that seed piece decay has progressed to the point where it would be impossible for the sprout to establish itself as a plant.

Variety resistance to high temperatures has been shown throughout this experiment. The Houma tubers and sets appear to be the most resistant to seed piece decay at high temperatures. This data coincides with that found by Cordner (10) in some unpublished data taken at the Oklahoma Experiment Station. The variety Houma made a better stand of plants with the resultant higher yield for the fall crop of 1938.

In conclusion, a brief review of the results of all three series follows: Sprout growth inhibits seed piece decay; and sprouting before planting in soil at a high temperature may enable a set to establish a plant, whereas unsprouted sets may fail. Decay is inhibited in that tissue which is nearest the sprout. The meristematic tissue of the growing point of the sprout is more easily injured by high temperatures than the more mature basal parts. Seed piece decay increases rapidly above 90°, and at 95° very little if any germination takes place due to the prevalence of seed piece breakdown.

Thus the question arises as to just what specific temperature may be the limit for the emergence of sprouts. This problem was investigated in Experiment II.

EXPERIMENT II

CRITICAL TEMPERATURE FOR SEED PIECE DECAY

During the previous experiment an optimum germination temperature was always considered in order to determine normal response. Since the data secured at 90 and 95^{o} showed that seed piece decay was prevalent at 90^{o}, but occurred much more rapidly at 95^{o}; it was concluded that the critical temperature for decay of the seed piece must be between 90 and 95^{o}.

The experiment was set up as follows: Four kinds of seed pieces were used, (1) sprouted cut, (2) sprouted whole, (3) cut, and (4) whole. Four flats of the respective treatments were placed in each cabinet, one flat being placed on each shelf. Each flat contained 24 sets, which made a total of 96 sets in each cabinet for each treatment.

As the experiment progressed, the various treatments did not respond uniformly in any one cabinet. This led to an investigation which disclosed that the temperature varied from shelf to shelf. This variance was uniform in each cabinet, the top shelf (shelf 1) being the same temperature at which the thermostat was set. The lower shelves had an increase in temperature as follows: Shelf 2, two degrees above that of shelf one; shelf 3, two degrees above that of shelf 2; and shelf 4, which was just above the heating unit, four degrees above that of shelf 3. The soil temperature was three degrees lower than the air temperature at any one shelf.

There is not a perfect trend in the data secured because the flats on the lower shelves dried out more rapidly, there was the inherent resistance of the individual sets to seed piece decay, and because of the inexplainable fact that some of the treatments showed better growth and emergence at 95 than at 92°.

The data in Table IV shows the percent of decayed tubers at the close of the experiment. Data on sprout emergence is not shown because the multiplicity of sprouts that emerged at the soil surface caused a confusion in taking the count. Upon removal of the tubers from the flats, it was found that many of the sprouts that had emerged were lateral branches from only one sprout, and the original sprout could not be traced back to the set because the seed piece had completely disintegrated. The table then was set up in terms of the percent of decayed sets from the original number (96) of sets of one treatment at each thermostat temperature for each cabinet.

It can be seen from the data in Table IV that 90° is approximately the critical temperature for the seed piece decay. All tubers will rot if left in this temperature for a sufficient period of time, provided the sets have not been sprouted previous to planting. The same amount of decay that occurs at 90° will occur in a shorter period of time if the temperature is raised above 90°.

At 95°, as mentioned in Experiment I, the sprout tip was injured on emergence which caused new laterals to be formed. This indicates that 95° may be considered to be the temperature limit above which the seed piece will not establish a plant.

The analysis of variance (Table V) was calculated on the basis of sound tubers in each flat of the respective treatments. From this data it can be seen that the kind of seed piece was the only factor of significance. This may be partially explained by the fact that sprouted whole sets did so much better at all temperatures on every

TABLE IV PERCENT OF DECAYED SETS FOR EACH TREATMENT AND TEMPERATURE

Treatment	Temperature 90°	92°	95°	Average
	Percent Decayed			
Sprouted Cut	72	63	85	73
Sprouted Whole	31	54	45	43
Cut	47	77	83	68
Whole	87	97	96	93
Average	59	72	78	

TABLE V ANALYSIS OF VARIANCE FOR EXPERIMENT II

Source	Degrees of Freedom	F Values	F value for 5% level*
Total	47		
Cabinet Temperature	2	1.08	3.55
Treatment	3	3.54	3.16
Shelf	3	1.72	3.16
Treatment and temp.	6	0.29	2.66
Shelf and temperature	6	0.19	2.66
Shelf and treatment	9	0.81	2.46
Error	18		

*Taken from Snedecor's Table of F Values (38).

shelf than all other treatments. Temperature appears to be insignificant in this data because the results from the sprouted cut and sprouted whole treatments were reversed at 92 and 95°.

This data indicates that cut sets have shown better results than whole sets which is in agreement with data found by Kenworthy (21).

The results from this experiment were unsatisfactory in that the exact critical temperature for seed piece decay was not determined, but these results strongly suggest that about 90° is the critical temperature for the unsprouted seed piece. This experiment served to substantiate Experiment I in that it was proved once again that sprouting of the whole seed piece previous to planting will enable the set to become established before the seed piece decays, while sets receiving other treatments may decay before a sprout emerges.

EXPERIMENT III

GERMINATION AND DECAY IN POTATO SETS IN RELATION TO COATING THE CUT SURFACE OF THE SETS WITH PARAFFIN

The data of Experiment I indicated that whole sets resisted decay more than cut sets, while in Experiment II the opposite was true. This was an effort to determine which of the two types of seed pieces was better.

Appleman (3) states that cutting of the tubers increased respiration and that this was a mild dormancy-breaking treatment. Though all of the potatoes used in this experiment were well out of the dormant period, a test was made to determine if the cutting itself had a preservative action, or whether the newly cut surface allowed gas exchange and thereby provided accelerated respiration rates at high temperatures.

All of the potatoes were cut, and one-half of the cut tubers had the cut surfaces covered with a coat of paraffin. This was done in order that the tubers would all receive the same treatment as to cutting; yet the paraffin surface would cause the potatoes to react in the same manner as whole tubers with reference to gas exchange.

One- half of each lot of tubers was sprouted before placing to germinate in the cabinets. The various treatments were as follows:

	Paraffined		Not Paraffined	
	70°	90°	70°	90°
No. of sprouted sets	36	36	36	36
No. not sprouted sets	36	36	36	36

The results of this experiment are found in Table V.

TABLE V GERMINATION AND DECAY OF POTATO SETS IN RELATION TO COATING THE CUT SURFACE WITH PARAFFIN

(Results of Experiment III

	SPROUTED				NOT SPROUTED			
	90°		70°		90°		70°	
	Par.	Not Par.	Par.	Not Par.	Par.	Not Par.	Par.	Not Par.
Variety Triumph Per Cent								
Sound	0	8	78	88	0	0	46	86
Rotted	100	92	22	12	100	100	54	14
Sound, not emerged*	0	8	3	3	0	0	16	3
Sound, emerged	0	0	78	89	0	0	43	83
Rotted, emerged	92	92	19	8	0	0	41	11
Rotted, not emerged	8	0	0	0	0	0	0	0
Days for 50% emergence	6	5	4	4	0	0	4	4

*Emergence of sprouts above surface of the soil.

The result of coating the potato with paraffin may be seen in Figure 8.

All of the paraffined tubers began to show blackheart in the center of the cut surface of the tuber and the various stages of breakdown could be clearly seen through the paraffin film. This indicates that blackhearting, the accumulation of carbon dioxide and the lack of oxygen, occurs farthest away from the periderm. In the light of the results found by Magness and Diehl (26), the collection of carbon dioxide in the paraffined potatoes would have been sufficient to cause injury at 90°. Magness (25) found that carbon dioxide could be as high as 30 % of the composition of the intercelluar gases at 80°. According to Kidd (22), this would mean that it would be sufficient to be injurious and perhaps could be the direct cause of the death of the internal tissue of the potato.

The results show that the whole potato does not grow as well as the cut potato at either 70 or 90°, but contrary to that which was first expected, the paraffin-coated potatoes at 70° germinated first, but grew slower after germination.

From Table V it can be seen that at 90° there were more sprouts emerged above the surface of the soil when the potato had been sprouted slightly before planting than when the potato had not been sprouted. In the 70° temperature group there was a greater emergence of sprouts above the surface of the soil for the sprouted potatoes than those that were not sprouted. Also, the number of sound tubers was greater when the tubers were sprouted previous to planting and when they possed a cut surface free from the coat of paraffin.

The rate of sprout emergence and subsequent growth of the

Paraffined
90°

Not Paraffined
90°

Fig. 8. Paraffined set showing presence of blackheart and decay in contrast to not paraffined set.

uncoated potatoes at 70° and 90° in contrast to the coated potatoes is indicative that slowing of the rate of gas exchange, which will result in the accumulation of carbon dioxide and a deficiency of oxygen in the potato tissue, is a hindrance to growth and brings with it possibility of increased seed piece decay due to blackhearting and physiological breakdown.

EXPERIMENT IV

SIZE OF TUBER IN RELATION TO GERMINATION AND DECAY AT HIGH TEMPERATURES

As was indicated by the previous experiment, the greater the distance of the internal tissue from the periderm, the more rapid and larger the area of blackhearting and seed piece decay. In some sections of Oklahoma it has been the custom to plant large whole tubers, as it was thought that they produced a better stand for the fall crop of potatoes.

In order to determine the differences between germination and blackhearting of large potatoes (average weight, 4 ounces), and small potatoes, (average weight, 1.8 ounces), four flats each containing 25 sets of potatoes (all Triumph variety) were set up. Two flats of each size were put at temperatures of 70 and 95^{o}.

Table VI summarizes the results of this experiment. These results show that the small potato will germinate more quickly at both temperatures and will be less likely to break down. The large potatoes developed blackheart in five days at 95^{o}, while the small potatoes did not develop blackheart until seven days had passed. Those at 95^{o} had to be removed in eleven days, as nearly all of the potatoes had ceased sprout growth and were rotting. Those at 70^{o} were allowed to remain until the twenty-first day before being removed.

These studies indicate that large seed potatoes do not aid in sprouting and germination; that small seed potatoes do germinate more rapidly and have a higher percentage remaining sound at high temperatures; and that small seed potatoes are able to remain in the soil at higher temperatures for a longer period of time before internal breakdown occurs.

TABLE VI EFFECT OF TEMPERATURE ON SPROUTING AND DECAY OF LARGE AND SMALL POTATOES

(Results of Experiment IV)

Percentage	Small potatoes 70°	Small potatoes 95°	Large Potatoes 70°	Large Potatoes 95°
Sound	76	51	46	38
Rotted	24	49	54	62
Sound Sprouted	76	38	46	38
Rotted sprouted	24	24	38	12
Sound not sprouted	0	13	0	0
Rotted not sprouted	0	25	16	50
Days for 50% germination	5	6	8	7

It is significant that more decay occurred with both the large and the small tubers at 95°. Any possible gain that might be made because of the additional food supply in the larger potato is lost at high temperatures due to the increased rate of seed piece decay. This was contrary to the data found by Haut (18) in the field in November, 1934. This data showed that large potatoes produced better stands and yields than small potatoes, however, this can be explained by the fact that conditions at Stillwater, Oklahoma that year were unusually favorable both in respect to moisture and temperature. The planting was made on August 27 after the fall rains had started. This late planting was necessary because dry weather had prohibited planting earlier. Thus the soil temperature was low and moisture was sufficient.

EXPERIMENT V

EFFECT OF VARIOUS CONCENTRATIONS OF ETHYLENE CHLORHYDRIN ON RATE OF RESPIRATION

Kimbrough (23) in his work on the storage of potatoes showed that respiration increased with the increase in temperature. It was desirable to know just what effects temperature and chemical treatment have on the rate of respiration and the resultant rate of seed piece decay.

In order to determine the effect of ethylene chlorhydrin on respiration, the apparatus was set up as previously described. Since the study was more or less preliminary and only chemical treatment was to be considered, constant temperatures were not used with Series I and II of this experiment, which was conducted in the laboratory. Two concentrations of ethylene chlorhydrin were applied to the tubers by the vapor method. They were, 1 cc. and 0.5 cc. per liter of air space. The method of treatment has already been described.

The amount of the chemical absorbed by the potato tissue was determined by the method outlined by Denny and Miller (13), and the results are tabulated below.

Treatment	Cubic Centimeters of 0.1 M Ethylene Chlorhydrin Absorbed
Series I:	
1 cc. per liter of air space	15.3
0.5 cc. per liter of air space	1.8
Series II:	
1 cc. per liter of air space	18.2
0.5 cc. per liter of air space	2.1

The data for this experiment are shown in the form of 3 point moving average graph. (See Fig. 9).

In Series I the rate of respiration started upward and reached its maximum during the first two days, and then the rate decreased

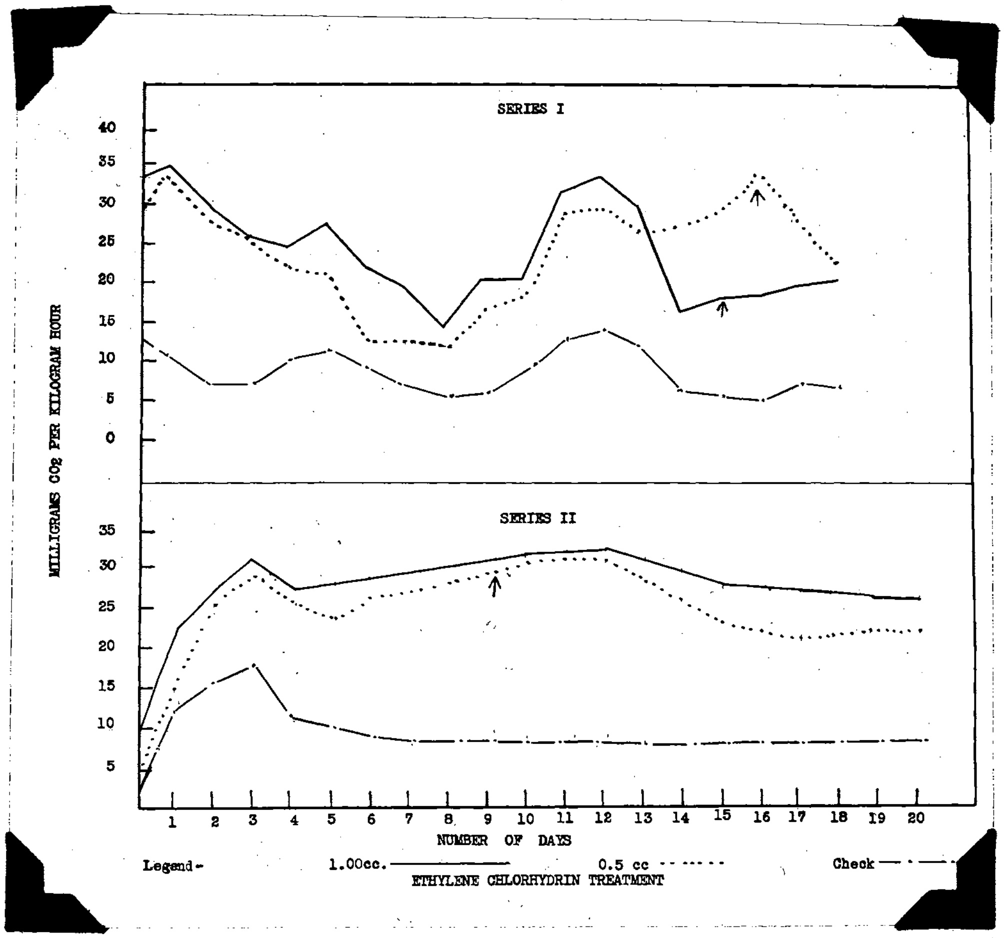

Fig. 9. Respiration response of potatoes treated with 1 cc. and 5 cc. of ethylene chlorhydrin per liter.

until the fourth day when the current that operated the vacuum pump was off for sixteen hours. (See Fig. 9 Series I) The respiration rate increased immediately, reaching its second peak on the third day after the current was off. It is supposed that this increase was due to the resultant accumulation of the carbon dioxide in the tubers and jars during the period when the air flow was halted.

Smith (37) found that carbon dioxide accumulated in the internal tissue of tubers when the outside concentration of carbon dioxide was increased. Kimbrough (23) found that with an accumulation of carbon dioxide in the tissue when the tubers were stored at low temperatures, there was an increase in the respiration rate far beyond the total amount that could be absorbed by the tubers. Wright (44) found that potatoes in cold storage accumulated carbon dioxide in the tissue, and that the rate of respiration increased after such an accumulation.

The fourth day after the current was off, the rate of respiration again declined. It is the belief of the writer that this sharp decline in the rate of respiration of the potatoes treated with 1 cc. concentration of ethylene chlorhydrin was due to the greater accumulation of carbon dioxide in the potato tissue, and possible resultant injury. As can be seen, the rate went below that of the 0.5 cc. treatment and remained below.

In the analysis of variance (Table VII), it was found that treatment was the principal source of variation, and that there was a variation from day to day which the writer attributed to the variation in temperature from day to day together with the presence of the normal variation due to physiological changes in the potatoes.

The greater variation in Series I than in Series II can be explained by the fact of normal variation coupled with the fact that

TABLE III ANALYSIS OF VARIANCE TABLE FOR EXPERIMENT V

Series I

Source	Degrees of Freedom	Mean Squares	F Values	F Value for 1% Significance
Total	59			
Treatments	2	1599.00	29.92	5.51
Daily Readings	19	169.50	3.17	2.40
Error	38	53.44		

Series II

Source	Degrees of Freedom	Mean Squares	F Values	F Value for 1% Significance
Total	50			
Treatments	2	1402	66.4	5.34
Daily Readings	16	199.4	9.4	2.51
Error	32	21.1		

the current was off.

Series II was conducted in order to verify the findings of Series I, that is, high respiration immediately following treatment followed by decline in rate until the sprouting begins (Note Fig. 9, Series II) It was found that the potatoes in the control chamber increased in rate of respiration, just as those that were treated increased, but not nearly as much the first three days of each experiment. This is attributed to the fact that carbon dioxide-free air was being drawn over the potatoes, which permitted the excess carbon dioxide in the tissue to be given off for the first three days, after which time the carbon dioxide resulting only from normal respiration was measured. This assumption would be true as regards the treated potatoes, and the difference in the rate of respiration of the untreated from the treated would be the actual amount due to treatment.

Weight loss of tubers in the respiration chambers in both Series I and II did not exceed 3% of the original weight of the potatoes placed in the chambers at the beginning of the test.

The potatoes in Series I were planted in flats and put in the greenhouse where the temperature was between 75 and 80^{o} during the germinating period. The flats received equal amounts of water and aeration.

The results of planting treated tubers are found on the following page.

RESULTS FROM PLANTING TREATED TUBERS

	Amount of ethylene chlorhydrin treatment		
	1.0 cc.	0.5 cc.	Check
Amount of ethylene chlorhydrin absorbed by the potatoes	15.3	1.8	
Number of sets planted	30	30	30
Number of sets rotted	30	9	28
Number of sets sound	0	21	2
Number of sets sprouted	30	30	22
Number sound, not sprouted	0	0	2
Number rotted, not sprouted	0	0	6
Days till 50% germination	3	5	12

The data indicates that seed piece decay increases with the increase of ethylene chlorhydrin absorption. Denny and Miller (13) found that any amount of the chemical over 15 cc. caused seed piece decay.

Treatment with ethylene chlorhydrin is desirable to promote rapid germination, but the amount taken up by the tissue should not exceed 15 cubic centimeters of 0.1 molar ethylene chlorhydrin as recommended by Denny and Miller (13) and verified by the writer.

For some unknown reason, a large percentage of the untreated potatoes decayed at the end of the experiment. Perhaps this may have been due to delayed sprouting.

The trends (Fig. 9) show that respiration increased with the concentration of the ethylene chlorhydrin treatment, and, together with the data from the field planting, indicate that high respiration rates and the increase in seed piece decay are correlated.

This experiment verifies again the supposition that sprouting has a preservative effect on the potato tuber. Any method that promotes sprouting without injuring the tuber will aid in seed piece preservation.

EXPERIMENT VI

EFFECT OF TEMPERATURE AND ETHYLENE CHLOPHYDRIN TREATMENT ON THE RATE OF RESPIRATION AND GERMINATION AND DECAY OF WHOLE POTATO SETS

As temperature has been the major factor that has been considered throughout the previous experiments, it was desirable to determine the relative importance of ethylene chlorhydrin treatment and temperature on the rate of respiration of whole sets.

As was shown in Experiment V, the respiration rate increases with the increase in concentration of ethylene chlorhydrin treatment. Since seed piece decay was increased so much by the 1.0 cubic centimeter treatment over that of the 0.5 cc. treatment, only one treatment, 0.5 cc. was made, and the other lot of potatoes were untreated.

The ethylene chlorhydrin treatment was given to 12 kilograms of whole potatoes at 82° for a period of twenty-four hours. Fifty-six tubers having a total weight of 2.12 kilograms were placed in each of the six respiration chambers. Three chambers contained treated tubers and three contained untreated tubers. A chamber containing treated tubers and a chamber containing untreated tubers was placed in each of the three constant temperature cabinets.

Flats containing twenty-four tubers that had received the same treatment as the tubers in the respective chambers were placed in the constant temperature cabinets.

The thermostats on the constant temperature cabinets were set at 70° , 90° , and 95° .

Fig. 10 is a graphic picture of the respiration activities of the

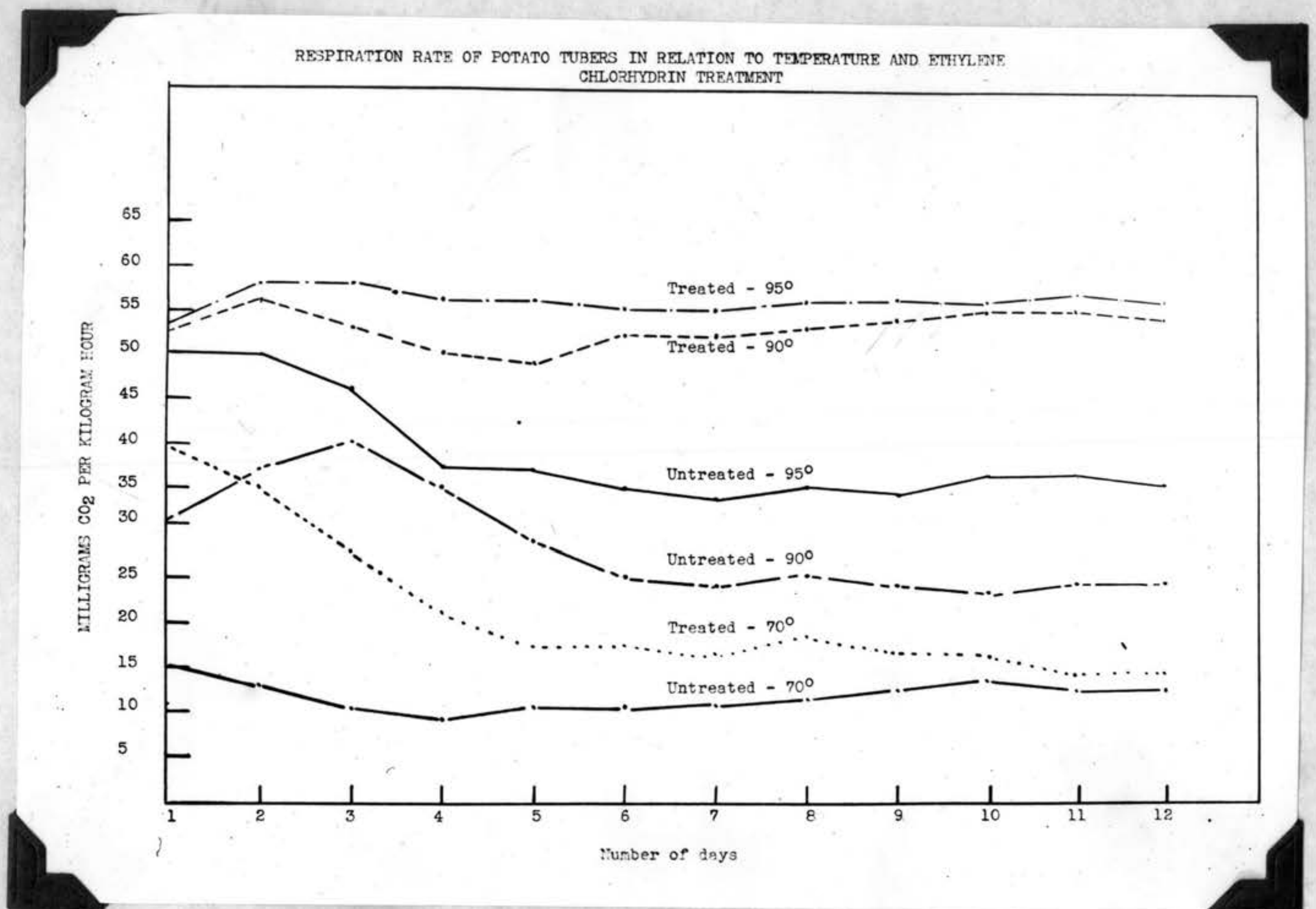

Fig. 10 Respiration Rate of Potato Tubers in Relation to Temperature and Ethylene Chlorhydrin Treatment.

tubers at each temperature for a twelve day period. These data indicate that at an optimum temperature of 70° the rate of respiration of treated potatoes will approach that of untreated potatoes in ten days; while at temperatures of 90° and 95°, the rate of respiration of treated potatoes reaches a maximum by the second day and then declines approximately three milligrams and levels off into a straight line.

This may be explained by the fact that physiological activities have been started in the treated potatoes; while in the untreated potatoes, the stimulation from temperature alone causes a rapid respiration rate due to temperature change from storage (these tubers had been in shed storage where the temperature ranged from 70 to 80°) to a constant temperature of 90 to 95°. The graph shows the maximum point of the rate of respiration of untreated potatoes at 90° to be on the third day, which is in agreement with Kimbrough (23). It should be noted that by the third day the respiration on untreated potatoes placed at 95° was well on the decline.

At constant temperatures of 90 and 95° the rate of respiration of treated potatoes was much higher than that of untreated potatoes and remained so.

Treated potatoes at 90 and 95° have approximately the same rate of respiration, while untreated potatoes have a much higher respiration at 95° than at 90°. This indicates that chemical treatment has more effect on increasing the rate of respiration than temperature.

In Table VIII the data indicates that the following factors had the greatest effect on respiration in the order listed: temperature, treatment, replicates (number of days the experiment ran). The replicates show the significance of the naturally declining rate of

TABLE VIII ANALYSIS OF VARIANCE FOR EXPERIMENT VI

Source	Degrees of Freedom	Mean Squares	F Values	F Value for 1% Significance*
Total	83			
Temperature	2	7202.5	182.8	4.92
Treatments	1	6120.0	155.3	7.01
Daily Readings	13	126.3	3.2	2.45
Error	67	39.4		

*Taken from Snedecor's Table of F Values (38).

respiration. This may be due to the physiological changes in the tubers.

The data shows the rate of decay to be in direct relation to the rate of respiration.

Sixth Day of Experiment

	Temperature		
	95°	90°	70°
Treated tubers:			
Rotted	14	10	0
Sound	10	14	24
Untreated tubers:			
Rotted	1	0	0
Sound	23	24	24

Twelfth Day of Experiment

	95°	90°	70°
Treated tubers:			
Rotted	24	23	9
Sound	0	0	10
Sprouted	0	0	10
Untreated tubers:			
Rotted	17	10	4
Sound	7	14	20
Sprouted	0	0	1

Fig. 10 and the above data definitely indicate that high respiration and the by-products of the respiratory activity are the cause of seed piece decay. That this cannot be due to the accumulation of carbon dioxide on the outside of the potato is definitely proven, because carbon dioxide-free air surrounded the potatoes at all times.

High temperature is almost as effective as chemical treatment in increasing the rate of respiration. The value of chemical treatment as an aid under these conditions depends upon whether a sprout may be started before seed piece decay so completely disintegrates the set that the sprout's source of food supply is destroyed.

DISCUSSION

High soil temperatures in Oklahoma at the time the fall crop of potatoes should be planted is the primary cause of seed piece decay. Under laboratory conditions blackheart precedes seed piece decay and may be produced within three days in whole, unsprouted potatoes planted in a soil temperature of 95°. This is in agreement with Mann and Joshi (27).

The writer found that high respiration is in direct relation to increases in temperature and sudden changes from low to high temperature, which agrees with Kimbrough (23). The combination of chemical treatment and temperature results in the highest rate of respiration. The data have indicated that the respiratory rate of chemically treated potatoes will approach the rate of untreated potatoes in five days at a temperature of 70°, while at 90° and 95° the treated potatoes will not decline to the same level of the untreated potatoes.

In these investigations cut unsprouted potatoes have been able to withstand high soil temperatures better than whole unsprouted potatoes. That this must in part be due to the rate of gas exchange is shown by the unparaffined potatoes decaying at a less rapid rate than paraffine-coated potatoes. This agrees with Kenworthy (21).

Much of the literature indicates that blackhearting and physiological breakdown are due to the accumulation of carbon dioxide in the internal tissue, but it is felt that this is only a part of the truth. The actual accumulation of carbon dioxide in itself is not the cause, but the combination of carbon dioxide and resultant deficiency of oxygen as indicated by Smith (37), Magness (25), Magness and Diehl (26), and Kidd (22) are the factors. As is known, the normal respiration of the potato must be carried on with oxygen, and it is the combination of carbon dioxide excess and oxygen deficiency in association with the relative impermeability of the periderm of the potato that results in injury and rapid seed piece decay when high soil temperatures are encountered.

The writer believes that seed piece preservation is due to aeration that the sprouts give the seed piece. Also, that the sprout epidermis is more permeable than the tuber periderm to gas exchange, and thus relieves the congestion of carbon dioxide, and, at the same time brings more oxygen into the seed piece.

The most critical period for the seed piece is from the time the set is planted until sprouting actually begins. Permitting the seed piece to sprout before planting eliminates a large portion of this period and enables a plant to be established before the seed piece completely rots.

Since high temperature alone is the principal factor causing seed piece decay, chemical treatment (unless used in large enough concentrations to cause injury) is an aid to seed piece preservation because it enables the seed piece to sprout more rapidly.

CONCLUSIONS

1. A soil temperature of 95°F. is the approximate limit at which sprouting of the seed piece will occur.

2. Soil temperatures of 90°F. or above, if continued for more than ten days after planting, will result in a poor stand, unless seed pieces have been sprouted before planting or unless they sprout immediately after planting.

3. Sprouting the potato sets before planting will possibly enable the potatoes to carry over until cooler soil temperatures occur.

4. A temperature above 90° is as effective in increasing the rate of respiration of potato tubers as chemical concentrations, provided the concentration is not too strong.

5. Chemical treatment is desirable to induce prompt sprouting of the sets when planting dormant tubers in soil at high temperatures.

6. Chemical treatment should be controlled so as to avoid seed piece injury.

7. Small, whole potatoes are better as seed pieces than large, whole potatoes.

8. Cutting the tubers to be used for seed pieces is an aid to seed piece preservation at high soil temperatures, when potatoes have not been sprouted before planting.

9. The respiration rate of potatoes treated with ethylene chlorhydrin will decline in eight days to about the same rate as untreated potatoes when both are placed in a 70° temperature.

10. At temperatures of 90 and 95 degrees a wide difference occurred in the respiration rate of untreated potatoes, but those potatoes having ethylene chlorhydrin treatment and placed at 90 and 95 degrees respired approximately the same amount. The rate of respiration of treated potatoes at 90 and 95° was much higher than that of untreated potatoes at the same temperatures.

SUGGESTIONS FOR FUTURE INVESTIGATIONS

The work which the writer has done has been but a small step in the vast possibilities for investigations on this subject. Mann[3] suggests the following

> "Would it be possible to see whether, by raising the temperature, all other conditions remaining the same, sprouting potatoes could be made to rot as quickly as dormant potatoes will at a lower temperature? Would it be possible to ascertain the effect of inoculating dormant potatoes with extracts from sprouted potatoes or from sprouts themselves? If the decreased susceptibility to rotting is due to substances formed in the sprouts, this should cause rotting to be slower in appearing than in un-inoculated potatoes."

Shull[4] suggests

> "It might be very advantageous to study the effects of temperature upon all of the known oxidative mechanisms that might occur in the potato. This would include the polyphenol oxidase system, the ascorbic acid oxydase system, the peroxidase system and catalase. Enzyme studies, coupled with analyses of the internal gases from injured stems of field grown potatoes would probably throw much light upon the behavior."

The writer suggests as possibilities for future study the determination of respiration rate of treated potatoes after sprouting has started at low temperatures and then changed to a high temperature; determination of just what a sprout contributes to the seed piece that helps to preserve it; investigation of physiological changes brought about when sprouting begins.

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[3] Ibid

[4] Shull, C.A., University of Chicago, personal correspondence, May 29, 1939.

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