FACTORS AFFECTING THE GERMINATION OF IRISH POTATO TUBERS, WITH SPECIAL REFERENCE TO THE PRODUCTION OF THE FALL CROP IN OKLAHOMA

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INTRODUCTION

In Oklahoma the commercial crop of Irish potatoes is grown during the spring season. Following the harvest of the spring crop there is usually ample time for the production of a second or fall crop, and many growers make a second planting to produce potatoes for their winter supply. The production of this second crop is attended by varying degrees of success and frequent failures.

The grower finds it convenient to use spring-grown tubers as seed for the fall crop. However, when spring-grown seed is used, the germination is slow and irregular, because the tubers have not emerged completely from their rest period.

At the time the fall crop is planted, soil moisture is frequently lacking and the soil temperature is quite high. A large percentage of the seed pieces decay in the soil without sprouting and a poor stand of plants is the result. This decay is quite definitely associated with high soil temperatures, and is generally attributed to the activity of rot-producing organisms.

These problems have been investigated to some extent by workers at the Oklahoma Experiment Station, and this thesis study is a phase of the work. Certain factors were selected for study with the following objectives:

(1) To determine the germination response under varying temperatures;

(2) To determine the direct cause of seed-piece decay;

(3) To devise means of preventing seed-piece decay; and

(4) To study the use of ethylene chlorhydrin as a means of abbreviating the rest period for fall-crop production.

REVIEW OF LITERATURE

This problem of fall-crop potato production, which is largely a local problem, has been investigated over a period of years by workers at the Oklahoma Experiment Station. However, this work has been carried on largely under field conditions with little control of environmental factors, and as a result the data are somewhat contradictory.

Rest Period

The "rest period" as will be used here, refers to that time in the normal life of the potato tuber in which sprouting will not take place even though external conditions are favorable for sprouting. "Dormancy" is used synonymously with rest period throughout the literature.

Causes

Appleman (4) suggests there are two schools of thought which stand directly opposed to each other as to causes for the rest period in plants: one school contends that the rest period is a direct response to changing external conditions; while the other considers it the result of fixed, hereditary, internal causes. In the older literature Grisebach (22) considered the yearly periodicity of plants of the temperate regions to depend entirely on a hereditary property, induced probably by physiological selection due to alternating external conditions through a long series of years; whereas Askenasy (6) claimed it to be due directly to external conditions. Sacks believed the rest period is due to a deficiency of soluble foods, and that the cessation of the rest is due to a gradual production of enzymes which make foods available. Fisher (20) studied the carbohydrate transformation in woody stems during the rest period, and concluded that periodicity of growth is conditioned by a periodicity in the processes of food changes, which in turn rest upon a hereditary periodicity of certain properties of the protoplasm.

According to Schimper (42) (the person who contributed the first real knowledge of tropical plant behavior) in regions where moisture and temperature are favorable the year around, many plants show a rhythmic alternation of growth and rest periods. He states,

> "Internal causes are mainly or solely responsible for the alternation of rest and activity in a nearly uniform climate. Such a rhythmic change is, however, never abandoned, for it arises from the nature of the living organism, and not from external conditions; its connection with external conditions is a secondary feature--an adaption."

Appleman (4) says,

> "The rest period of the potato tuber is not firmly fixed and hereditary. It is not of internal origin due to autogenic metabolic changes, as it can be entirely eliminated by means which maintain a proper adjustment between the bud tissue and external agents, chiefly oxygen. In nature the oxygen supply to the internal tissue is regulated by skin characters which are greatly influenced by moisture relations."

Howard (23) experimenting with a large number of trees, thought both winter and summer rests are caused by unfavorable external conditions. Euler (19) attributed the rest period to internal self-regulatory processes, and theorized that after-ripening would simply consist in certain changes during the rest period which weaken the synthetic processes.

Appleman and Miller (3) found that tubers harvested at different stages of maturity differed in composition when harvested, but that the composition of all was about the same at the end of the dormant period. They considered protein hydrolysis to be one of the important changes in the ripening of the tuber. Newton (38) also considered the ending of the dormant period to depend, in part, upon the activity of proteolytic enzymes, and the enzymes which convert amino to amide nitrogen.

Stuart and Appleman (48) later came to the conclusion that there is a very slight shifting in the relative proportions of the different nitrogen fractions in potatoes under any conditions during their natural storage life.

Rosa (39) found that the primordia of the vegetative sprouts develop during the later stages of tuber growth, as well as during the dormant period. At temperatures favorable for growth, the meristematic region is probably never inactive. In emergence from the dormant period, this activity increases greatly.

Factors influencing or associated with the rest period

Tuber maturity

Appleman (4) states that immature potatoes have a thin, slightly suberized skin which is quite permeable to both water and gases, and as the tubers mature, the skins become more suberized and more adherent to the underlying tissue.

According to Rosa (39) the more mature the potato when harvested, the shorter is the rest period. Werner (56) also found as length of time after harvest increased, tubers sprouted more promptly when planted, and that the most mature potatoes responded most promptly to the treatment with ethylene chlorhydrin. Tubers that were immature because of late planting sprouted more slowly than those which were immature from being harvested early, but when both lots were stored the same length of time, the former produced more sprouts.

Expressing the same idea, Wright and Peacock (59) found that the rest period of immature potatoes of all varieties averaged from 1 to 8 weeks longer than that of mature potatoes.

Variety

Rosa's work (39) shows that potatoes harvested when the tops were only partly dead, and stored at 72^{0} F. later showed the following germination response:

Variety	Days to emerge	% Emergence
White Rose	39 days	62 %
Early Rose	39	55
Green Mountain	42.5	57
Idaho Rural	50.6	34
American Wonder	51.0	60
Bliss Triumph	55.0	32
Irish Cobbler	56.5	38
Garnet Chile	56.6	52

Mature White Rose tubers emerged from dormancy in about 28 days, and those of Idaho Rurals in about 39 days. The immature tubers were somewhat dormant at the end of 66 days. The difference between tubers within a variety may be due to depth of eyes, according to Rosa. Deep-eyed tubers have a longer dormant period than shallow-eyed ones, which is probably because the bud primordia are so located as to exclude oxygen. With the late maturing potatoes of Irish Cobbler, Triumph, Early Rose and Spaulding Rose, the rest period was about 40 days shorter when the tubers were stored at 60^0 F. than when they were stored at 36^0 F. With Green Mountain and Russet Rurals the storage temperature had little effect on the rest period.

Wounding

Appleman (4) shows that cutting tubers is a mild dormancy-breaking treatment. He says that potatoes may be sprouted any time by removing the skins and supplying favorable growing conditions. He asserts this is not due to absorption of water from the exterior, as tubers with the skins removed will sprout in dry storage much earlier than those with skins intact.

Loomis (24) found that one-ounce clipped tubers grew more slowly than one-ounce pieces cut from four-ounce tubers from the same hill. He finds that larger tubers have a shorter rest period and respond to various dormancy-breaking treatments more readily than smaller sized ones. Rosa (40) also found that chemical treatment of small mature tubers planted whole is less effective in abbreviating the rest period than similar treatments on larger potatoes cut before planting. He says it is not known whether there is a more profound rest period in small tubers, or whether it is due to the additive stimulation of cutting.

The dormant period was prolonged, or a secondary dormancy was induced by cutting in advance of planting and storing at intermediate temperatures (used 34, 45, 56, and 72^{0} F.), according to Rosa (39). However, Wright, Peacock, and Whiteman (60) found that potatoes cut into pieces and then placed in storage germinated when planted as well or better than whole tubers that had been stored. The cut pieces usually produced sprouts quicker, had a more vigorous sprout growth, and matured from 7 to 10 days' earlier. The tubers were more uniform in size with fewer over-sized specimen.

In work conducted at this station, the data on cutting the tubers before planting have been rather inconsistent. Cutting the tubers has shortened the rest period, and given a higher percentage germination in some years, while in others, negative results have been obtained.

Chemical Treatment

The earliest work to shorten the normal rest period of the potato in the United States was done by W. B. McCallum in 1909 (27), using ethyl bromide, tetrachloride, ammonia, gasolene, and bromine. Since that time hundreds of chemicals have been used. Among the many used, only those which have given promise will be mentioned.

Vocha and Harvey (54), and Rosa (40) found that tubers treated with ethylene gas sprouted more rapidly than the untreated ones; while Crocker, Hitchcock, and Zimmerman (12) found that it inhibited sprouting, as did Elmer (17). Denny (14) also was unable to secure satisfactory results with the ethylene gas. The length of treatment, maturity of tubers, and the concentration of the ethylene gas probably accounts for these differences in results.

Guthrie (21) found that the sulphur compounds, or compounds which increase the pH and the capacity of the juice to reduce iodine in acid solution are effective in breaking the rest period. One of the sulphur compounds found to be very effective by Miller (30) was ammonium dithiocarbamate.

In Denny's work (16) sodium thiocyanate (Na S CN) and ethylene chlorhydrin ($Cl\ CH_2\ CH_2\ OH$) were about equal in their capacity for breaking the rest period, being more promising than any of the other chemicals. Rosa (40) has found that under high temperature conditions the thiocyanates are toxic.

Method

Denny (14) has used three methods of treatment with ethylene chlorhydrin: (1) Soak, (2) Dip, and (3) Vapor methods.

With the Soak method, as the name indicates, the tubers are placed in an ethylene chlorhydrin solution for a given length of time, then planted. Good forcing action is given with the Soak method, but Denny (14) does not recommend the method when good results can be obtained otherwise. In the Dip method, the tubers are dipped into the ethylene chlorhydrin solution, then brought out, and placed in an air-tight container for a certain length of time. With the Vapor method, the tubers are placed in an air-tight container with the ethylene chlorhydrin being placed in a shallow pan, or absorbed in some sort of material so that rapid evaporation will take place. After treatment in both the Dip and Vapor methods, the potatoes are allowed to air 12 to 24 hours before planting. According to most of the work that has been published there does not seem to be a great deal of difference between the Dip method and the vapor method. However, Stuart and Milstead (49) did find the vapor method much less effective than the Dip method, and the vapor treatment resulted in an appreciable amount of decayed seed.

Concentration

The concentration to use for treatment will vary slightly with the variety, and with the temperature, and as Denny (15) says, no doubt conditions for maximum effect will be found to vary with the stage of dormancy, with crops from different localities, or with the harvest from different years.

In treatment of whole tubers of the Bliss Triumph variety, he got satisfactory results by using 2 cc. of ethylene chlorhydrin per liter of air space for 24 hours. Denny (14) found that better results were given if whole tubers were allowed to stand in air after treatment for a day before planting. Results indicate that the effect of treatment holds over in the tubers during storage for at least three weeks.

Denny (16) has also found a favorable response with cut tubers using the dip method at 86^0 F. but when treated at 95^0 F. the seed pieces all rotted. After planting at temperatures below 68^0 F. treatment, using 30 cc. per liter of water was less successful in abbreviating the rest. The storage temperature for the 24-hour period after treatment must be below 89^0 F. in order to avoid injury to the potatoes, and should be higher than 59^0 F. to get maximum germination, according to Denny. The disadvantage of low storage temperature can be partly compensated for by increasing the concentration of the dipping solution to 60 cc. per liter of water, but injury above 89^0 F. can not be avoided by decreasing the concentration of the dipping solution.

Rosa (40) found that 1 cc. and 0.75 cc. per liter of air space with whole potatoes gave best results when the air was circulated in the chamber at 68 to 75^0 F.

Humidity

According to Loomis (24) low humidity in storage gave a shorter rest period for a given temperature, but resulted in injury with long exposures. He found at high temperatures those tubers stored in moist moss showed least injury, and made the best growth. He concludes that storage in damp moss had no direct effect upon the rest period, and suggests the beneficial effect of the moss lay in conservation of moisture rather than in a reduction of suberization.

In using a relative humidity of 75% at 40^0, 55% at 71^0, and 60% at 86^0 F. for storage, Rosa (39) found that at 40^0 and 86^0 F. the humidity around the potato had no effect on subsequent sprouting. However, at intermediate temperatures, 71^0 F., the moist samples in every case sprouted much more rapidly than the dry, or check lots. He suggests that the moist storage at 40^0 F. does little to abbreviate the rest period, due to the limitation of the low temperature, and at 86^0 F. the effect of moisture is not generally additive, because the high temperature itself brings about the most rapid termination of the rest that is possible. Smith (44) also found when tubers were stored moist at 77^0 F. the rest period is appreciably abbreviated and the skin becomes more permeable to gases.

Smith (43) found no apparent relation between the average precipitation and yield per acre where the rainfall exceeded ten inches for the growing period. However, with field observations, Loomis (24) suggested that a secondary dormancy might be induced in chemically treated seed by planting in a soil where the moisture content is low.

Temperature

Muller-Thurgau (36) in 1882, stated that storage of tubers at 32^0 F. shortened the dormant period. However, his chief experiment involved ten tubers harvested and held at 32^0 F. for 40 days, then planted at 68^0 F. He used no control or check. Newton (38) working at the California Agricultural experiment station reported that immature tubers stored at 41^0 F. sprouted slightly more rapidly than similar tubers stored at 68^0 F. His experimental lots, while very small (10 sets per culture) still gave consistent differences.

Muller-Thurgau and Schneider-Orelli (37) found that exposures of tubers to temperatures of 101, 104, and 108^0 F. for from 4 to 8 hours resulted in an increased respiration rate after their removal to a lower temperature. This indicates there is an increased oxygen intake by the tuber after exposure to high temperatures, which may be important in connection with increased growth rate. These writers concluded that the effect of heat is fundamentally a weakening of the protoplasm like that ensuing normally as the age of the tuber increases.

Sound tubers of some varieties can be kept for nine days at temperatures as high as 107^0 F., while others develop blackheart at these temperatures, according to Ajrekar and Ranadive (1). Appleman (4) found that heating potatoes at 104^0 F. for eight hours in a moist chamber hastened sprouting though the same treatment in a dry chamber had less effect.

In every case Rosa (39) found that tubers stored at higher temperatures (used 26 and 36 days' storage at 32 and 74^0 F. sprouted somewhat more rapidly than at low temperatures when the plantings are made in the early and middle portions of the dormant period. He also found when tubers are stored at 39, 47, 74, and 86^0 F. for 25 days that the tubers stored at 86^{0}F. sprouted more rapidly when planted than those which were stored at lower temperatures. Storage at 40^0 F. may retard sprouting somewhat as compared to 68 to 74^0 F. With undercooled tubers (temperature was not known, but half of the tubers were frozen) he found that the tubers sprouted somewhat more rapidly than those which had been stored at higher temperatures. Rosa thinks the effect of high temperature may be due to some direct physiological effect beside the increase in the normal growth rate of the bud primordia and to the increased rate of chemical reactions in the cells associated with high temperatures.

Using 40, 77, 86, and 95^0 F., Smith (44) found that all varieties acted similarly, the respiration rate being highest at 95^0 F., and decreasing in order through 86, 77, 40^0 F. Contrary to the above work, he found those tubers stored at 77^0 F. had the shortest rest period, with 86, 95, and 40^0 F., following in order.

Wright and Peacock (59) found that on an average with all varieties the rest period was shortened at 70^0 F. to practically half of that at 40^0 F. Stuart and Milstead's (49) studies proved the efficacy of storage temperatures around 86^0 F. for shortening the rest period of tubers.

The highest rate of respiration of tubers occurs immediately after harvest, according to Smith (51), the rate decreasing rapidly even if the tubers are placed at 45 to 65^0 F.

<u>Relation of Respiration to Rest Period</u>

Lowering the temperature between 113 and 41^0 F. causes decreased respiration, as indicated by the carbon dioxide production, according to Van't Hoff-Arrhenius rule--a lowering of ten degrees roughly halved the respiration rate. The minimum rate of respiration is at approximately 38^0 F. according to Bennett and Bartholomew's (8) work.

Also Braun (9) found the maximum respiration at about 113^{0} F. and the minimum at about 41^{0} F., below which the respiration increases again until 32^{0} F. is reached. It then falls off again as the temperature is lowered.

Smith (44) found the product of respiration rate and the length of rest period of each of the four varieties (Early Ohio, Bliss Triumph, White Rose, and Irish Cobbler) to be almost equal. He found no direct correlation to exist between rates of respiration at various temperatures, and length of the rest period. However, he found a direct relation between the rate of respiration of each of the varieties and lengths of their rest period when stored at 77^{0} F.

Michaels (29) found the higher respiratory rate of the small tubers to be due to their greater surface area in proportion to their volume. The number of lenticels per kilogram of tubers to increase from large to small tubers, and he found the amount of carbon dioxide liberated per kilogram of tubers to increase from large to small tubers. However, the amount of carbon dioxide respired per lenticel decreases from large tubers to small. He thinks this is probably due to the higher number of lenticels per unit of surface area in the small tubers.

Miller (32) observed a maximum respiration rate 50 to 60 hours after the tubers were treated with ethylene chlorhydrin (24-hour treatment), then a gradual decrease until a value approached, corresponding to untreated tubers, in about a week after treatment.

Although treatment with many chemicals which break the rest period increases the sugar content of potato tubers, Miller (32) found no correlation between the rest period and sugar content.

Treatments which increased the carbon dioxide output also usually caused large increases in sugar content, but these increases did not occur until after the peak of the higher respiratory activity had passed, according to Miller, Guthrie, and Denny (34).

Relation of Temperature to Germination

Erwin and Rudnick (18) concluded that 40° F. is probably the lowest temperature at which the potato will sprout.

Bushnell (10) recommended that potatoes should not be planted in a hot soil as seed-piece decay is induced.

Loomis (24) in working with germination temperatures of ethylene chlorhydrin treated and untreated tubers secured the following results:

Treated Tubers		Untreated Tubers	
Germination Temperature	% Germination	Germination Temperature	% Germination
68° F.	60.0	68° F.	5.0
77	77.5	76	80.0
86	92.5	83	87.5

Relation of Blackheart Injury to Sprouting

Bartholomew (7) in 1915 thought that the accumulation of carbon dioxide, or the products of respiration, and the lack of oxygen brought about death of the cells. Under laboratory conditions he produced blackheart at 101 to 111° F. in from 15 to 24 hours. The optimum temperature for its development was at 108 to 111° F.

Stewart and Mix (56) found with a volume of air equal to the volume of potatoes, a confinement of 10 to 12 days is sufficient to produce blackheart, provided the temperature is around 70° F. At 55 to 60° F. about 20 days are required, and at 40° F. a still longer time is required, being from 23 to 40 days. Tubers confined with less than about ten times their volume of air are unable to do more than barely start sprouts. For normal sprouting about nineteen volumes of air per volume of tubers are required. They conclude if tubers are sound and normal in appearance it is unlikely that they have been injured for seed purposes by storage conditions, and that tubers severely affected should not be planted, but slightly affected tubers may be planted.

Mann and Joshi (26) in India found that tubers heated in open wire baskets at ordinary air temperatures of 27 to 86° F. remained sound for periods longer than 12 days. When heated at 97° F. under the same conditions of aeration, blackheart occurred in about 6 days. At 106 to 108° F. injury was very marked in 2 days. When 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 at 81 to 86^0 F. in 6 to 12 days. At 97^0 F. injury had occurred on the third day. Observations by Bennett and Bartholomew (8) have shown that continuous heating occasionally produced blackheart at temperatures as low as 77^0 F.

Davis's work (13) agrees with Mann and Joshi's (26) findings, as he produced blackheart in the laboratory at a temperature of 113^0 F. in a carbon-dioxide free atmosphere in which there was an abundance of oxygen available. He says 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 intercellular gases contain more than 50% carbon dioxide, and less than 4% oxygen. This condition is followed by increasing permeability of the protoplasm, together with other changes. At the temperature used, blackheart is apparently the result of high respiration, and the failure of the gas exchange to keep pace with the respiration rate.

Davis says that temperature may exert a direct effect above 101^0 F. as some evidence has been obtained that this temperature becomes critical for the maintenance of normal water relations of cells.

Bennett and Bartholomew (8) found at high temperatures of 95 and 104^{0} F. blackheart appeared at approximately the same time. At the time blackheart occurred the amount of carbon dioxide evolved was relatively low, and the oxygen residue in the jars relatively high. At temperatures of 86, 77, and 68^{0} F. there was a difference in varietal behavior. Rural New Yorker and Green Mountain Junior tubers were injured two or three days earlier than the Netted Gem variety. At these lower temperatures, carbon dioxide was relatively high, and oxygen relatively low at the time of injury. Their work agreed very closely with the other workers' investigations, in that blackheart was produced at 95 and 104^{0} F. by heating tubers in normal air; at 86^{0} F. it occurss infrequently, and at 77^{0} F. very rarely.

Treatment of Seed-Piece to Prevent Decay

As Rosa (39) says, practical advantage may be made of the fact that cut sets from medium to small tubers are less subject to decay than sets from larger tubers, and that fully matured tubers before harvest have less decay than those harvested immature. Also tubers stored at high temperatures 71 to 86^{0} F. or under moist conditions at lower temperatures decay less when planted than tubers which have been in cold storage.

That vegetative activity offers resistence to the advance of seed-piece rot is pointed out by McMillan and Meckstroth (28). Also that other factors, such as vigor of the seed, and aeration, commonly prevent or retard seed-piece decay even when the soil temperature is well suited to it.

Suberization

Appel (2) and other workers have noted that the cut surface of the tuber "heals" so that a new protective layer is formed which excludes fungi as effectively as the original periderm of the tuber. Appel (2) found that this layer appeared 48 to 60 hours after cutting, and was completed in two additional days. Priestly and Woffenden (41) studied conditions under which the healing process takes place. They found that a warm, moist atmosphere with normal oxygen content is most favorable. They show that under these conditions the cut surface is "blocked" in 24 to 48 hours by a deposit of a fatty substance on the wounded surface. Two to five days later a cork layer forms as a result of rapid cell division below the blocked surface. This results in a permanent protective layer.

Montemartini (35) concludes that the formation of cork after wounding the tuber is dependent on light, humidity, temperature, and the age of the tuber, and as others have stated, small doses of copper sulphate, copper acetate, and ethyl alcohol may aid in its development. It may also be stimulated by certain saprophytic fungi (Penicillium, etc.). He says cork production is later near the eyes than at some distance from them.

Eyes exercise in their vicinity a retarding action on the formation of wound tissue.

Contrary to most of the work done, Appleman (4) found that drying causes rapid suberization of new skin and exposed surfaces. He says that suberization greatly reduces permeability of the skin to water and gases. He found when tubers are cut in half transversely, or cut into half-inch slices, the buds on the stem half located near the exposed surface will sprout much earlier than normally, provided suberization of surface cells is prevented. This may be accomplished by laying on wet soil. He says that sprouting is not due to water absorption, because the rest period may be greatly shortened in dry storage if drying of the exposed surface is prevented by covering with a thin layer of paraffin.

Rosa (39) found that periderm formation did not take place, to any marked extent, at 32^{0} F. The other cut lots showed decay in direct proportion to the increasing temperature (32, 45, 55, and 72^{0} F.) Furthermore sprouting was much retarded in these lots. The cut sets at 45, 55, and 72^{0} F. formed a periderm over the wounded surface, which interferred with gas exchange, hence retarded sprouting, yet did not protect the sets from decay when planted in the soil. The decay was greater than those cut at planting time. In another experiment Rosa placed the cut tubers in wet sawdust in shallow trays at 72^0 F. for 6 days. These showed the least decay, and sprouted somewhat more rapidly than the check.

Suberization first appeared in 2 days in tubers at 68^0 F., but it was not detected until the sixth day in tubers at 46^0 F., according to Smith (45). The wound periderm was first noted on the third day of storage at 68^0 F., whereas there was no periderm layer at the end of 12 days with storage at 46^0 F.

Priestley and Woffenden (41) have found in the process of wound-periderm formation the cut surface first turns dark, due to oxidation products. Later this black or brown stain is covered by a white, partially crystalline deposit, consisting of inorganic salts, starch, etc. If the cut potato is exposed to sunlight or very dry air, this outer crust of dried matter becomes exceedingly hard, and later cracks. The blocking deposit of suberin forms a continuous layer around the potato, and is found along every wall of every cell at a certain depth below the injured surface. This deposit is of a fatty nature, formed only in the presence of air, and precedes the formation of the cork phellogen. The cork phellogen formation rate varies with the variety, with temperature, and probably with other conditions. This blocking deposit will restrict the loss of water by evaporation. The gaseous exchange will also be impeded by this layer.

Within the blocked substance is formed a cork meristem. The original cell walls, as well as the new cells, are impregnated with a suberin-like substance. The phellogen produces a number of rows of very regular cells. If the potatoes are cut and left for a time in sunlight, the continuous deposit of suberin is lacking, and the potatoes remain much more susceptible to disease. Priestley and Woffenden say that cutting the tubers in the sunlight or exposure to too dry an atmosphere is responsible for the fungus attacks.

Artschwager (5) found at 43 and 41^0 F. and 70% humidity, suberization was marked after a period of 53 days, but no periderm developed. At 95% humidity, however, a well developed periderm was noticeable. He also found that different tubers often react differently. At low temperatures variations in relative humidity produce less effect on the evaporation rate than at high temperatures. At 54^0 F. for 6 days at 64% humidity, only the initial stages of suberization were evident. No periderm was formed at temperatures lower than 45^0 F. At that temperature the first periderm cells appeared in 9 days; at 21^0 F. and above, periderm cells were seen after 2 days regardless of the variety.

Chemical Treatment

The only experimental work that was found on treating the seed-piece with chemicals to prevent decay was that by Clayton (11). His work covered a period of four years, and dealt with treating and storing. He found many chemicals actually promoted decay. This was true of all mixtures containing copper compounds, sodium bichromate, sodium fluoride, dinitrophenol, and beta naphthol. Mixtures containing sulphur, gypsum, lime, calomel, and creosote appeared harmless. Field experiments showed that sulphur, and in some instances gypsum, reduced stands, and yields when the seed was cut, treated, and stored three to four weeks before planting. Treatment with sulphur and lime, equal parts by weight, or with charcoal dust containing 3 per cent creosote, increased the stand and yield of potatoes cut three to four weeks before planting as compared with untreated seed, but had no effect on seed cut a week to ten days before planting.

With the exception of the sulphur and lime combination, none of the chemicals had any visible effect on the corking over of cut surfaces, and all lots appeared in perfect condition at planting time. This was true even of the sulphur treated lots, although they decayed badly following planting. Under field conditions, sulphur and lime dust resulted in the formation of a thicker, tougher protective layer over the cut tuber surfaces than did any of the other materials and seemed best and most practical. All potatoes were kept in a storage cellar which was ideal for cut seed, and germinated in the field.

EXPERIMENTAL DATA

As stated in the general introduction, when the spring crop of potatoes is harvested the tubers are in a state of rest, the soil temperatures are quite high, and the moisture is frequently limited in the soil. If the spring crop of tubers is to be used for the fall planting breaking of the rest period is usually necessary in order to have the crop mature before frost. Due to the fact that there may not be enough moisture in the soil to replant at once, the tubers are often stored for short periods of time.

In planning these experiments, consideration was given to the conditions under which the grower must labor, in an effort to work out something that might be applicable to his needs. Therefore, the materials and environmental conditions used in all cases are those that are capable of being applied by the grower.

Due to the fact that considerable work has been done on treating the tubers with various chemicals for breaking the rest period, the commercial form of ethylene chlorhydrin (40% solution) was decided upon without further investigation. The vapor method was thought to be more practical than the dip method, and was used exclusively for this work. The vapor method as used by Denny (15), with some alterations, has been used in all of these experiments.

Treatment temperatures and concentrations have been worked out quite thoroughly by Denny (16), therefore, it was thought unnecessary to go into any great detail on this phase. However, the possibility of high storage and soil temperatures complicate matters a great deal. Therefore, it has seemed necessary to investigate some of these phases further.

EXPERIMENT I

The purposes of this experiment are: to determine the effect of ethylene chlorhydrin treatment and storage temperatures; the effect of length of storage after treatment; and the effect of temperature on the germination of potato tubers.

When this preliminary work was begun it was impossible to obtain Oklahoma spring-grown tubers, so Florida-grown Bliss Triumph tubers, harvested around March 6, 1937 were used.

On April 4, whole tubers were treated with ethylene chlorhydrin in two incubators at 75, and 90° F. respectively, with the potatoes lying on cross-bar shelves. The ethylene chlorhydrin, at the rate of 2 cc. per liter of air space, was poured into pie pans, and placed on the top shelf of each of the incubators. Fans circulated the air, and all possible precautions were taken to make the incubators air tight. The tubers were treated in this manner for 24 hours, after which the doors and ventilators were opened, and the potatoes were allowed to air for 24 hours.

For some reason the vaporization was unequal in the two incubators. When the cabinet at 75° F. was opened, after treatment, the whole laboratory in which the cabinet was placed seemed to be filled with ethylene chlorhydrin fumes, while the incubator at 90° contained only a perceptible amount of the gas. There was also a proportionately larger amount of the liquid left in the pan at 90 than at 75° F. This would indicate that at 90° F. the vaporization was not so complete, and also that perhaps the fumes may have escaped from the incubator.

A portion of the tubers treated at 75 and 90° F. was stored at 90, and a portion was stored at 75° F. for 4-, 10-, and 21-day intervals. It should be noted that during storage some decay took place, and at the end of each of these periods the decayed tubers were discarded in all of the lots. When cutting the tubers to plant, decayed portions were discarded, and only the sound pieces were retained for planting. An untreated control lot was stored in a cellar where the temperature ranged from 45 to 55° F.

Tubers from each treatment were removed from storage at the end of each storage interval for planting. The tubers were cut into approximately one-ounce pieces, care being taken to get an equal distribution of apical and basal pieces in each lot. Then the sets were planted in electric-heated hotbeds which were thermostatically controlled (General Electric thermostats as used for hotbeds). The thermostats of the three hotbeds were set to cut-off at 68, 83, and 93^{0} F. respectively. The hotbed soil was composed of one-half sand, and one-half sandy clay loam.

At the end of the 21-day storage period, when all of the tubers were removed, a photograph was taken of representative tubers of the various treatments (see Figure 1).

Emergence records were taken at two-day intervals. Sprouts were counted just as soon as they appeared above the soil. After a period of 50 days when all sprouting had ceased, the sets were dug up. Records were taken per treatment temperature, storage temperature, storage interval, and per germination temperature, then the data were organized in order to present the results shown in the following tables:

Table I shows the per cent germination and decay for tubers of the various treatments as listed.

Table I. Combined Effect of Treatment and Storage Temperature on Germination Percentage and Decay of Potato Tubers

Treatment Temperature	Storage Temperature	No. sets planted	% Germ.	% Decay
75° F.	75° F.	162	30.2	69.8
90	75	162	30.2	69.8
90	90	153	24.5	74.5
75	90	105	6.7	93.3
Untreated	45 to 55	54	56.4	43.6

Under conditions of this experiment, the treatment at 75° F. followed by storage at 90° F. proved quite destructive to the tuber since 93.3% of the sets decayed after planting. The more concentrated vapor in the treatment at 75° F., followed by storage at 75° proved to be equal in germination value to the mild treatment at 90°, followed by storage at 90° F.

This would indicate that a high concentration of the ethylene chlorhydrin vapor during treatment, followed by storage at a high temperature is to be avoided. This confirms Denny's work in treating cut tubers with ethylene chlorhydrin (16).

The effect of length of storage upon the subsequent germination and decay of tubers treated with ethylene chlorhydrin is shown in Table II.

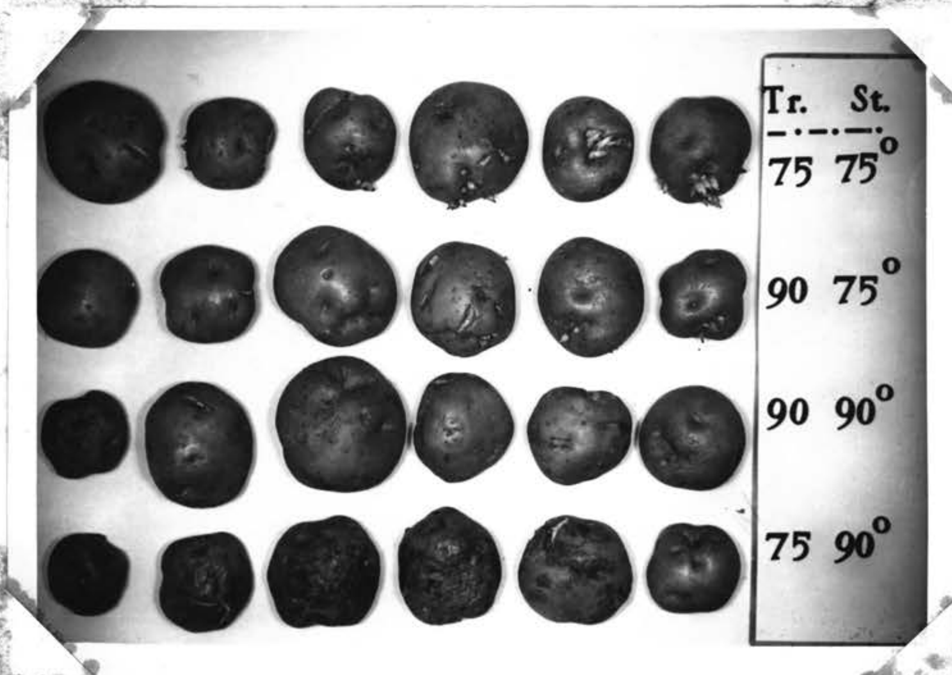

Fig. 1. Showing the effect of treatment and storage temperature as presented in Table I.

Table II. Germination and Decay of Potato Sets When Tubers are Stored for Intervals after Treating with Ethylene Chlorhydrin

Storage Interval Days	No. Sets	% Germination	% Decay
4	216	19.8	78.2
10	210	9.0	88.1
21	159	42.8	52.4

According to the results of this experiment, the 21-day period gave the highest per cent germination with less decay, being followed by the 4-day period.

The reason for this is perhaps because the storage conditions reduce the potentiality for sprouting; therefore, the 4-day storage interval, which only had a short storage period, gave a higher per cent germination than the 10-day interval. However, at the end of the 21-day period most of the tubers which were going to decay had already done so, and were discarded; thus, a greater proportion of sound tubers were planted. It might be that the greatest losses had occurred by the end of the 21-day period; therefore, the highest germination percentage would be expected.

As has already been stated, the control lots of tubers were stored in a cellar at 45 to 55° F. At the last planting date a lot was removed, the tubers cut into sets, and these planted in the three hotbeds along with sets which had been taken from tubers stored for different intervals.

Table III presents the germination percentage and decay of the control or untreated potatoes in comparison with those of the treated lots. The data are presented according to the soil temperatures at which the sets were germinated.

Table III. Effect of Germination Temperature on Ethylene Chlorhydrin Treated and Untreated Tubers

Soil Temperature	Treated No. Sets	Treated % Germ.	Treated % Decay	Untreated No. Sets	Untreated % Germ.	Untreated % Decay
68° F.	194	44.3	50.5	18	61.1	33.3
83	194	23.7	75.8	18	16.7	83.3
93	194	6.2	93.8	18	0.0	100.0

It should be noted that the extent of seed-piece decay varied directly with the soil temperature both with the treated and untreated sets. The best germination resulted when treated or untreated sets were germinated at 68° F. The untreated sets at 68° gave a higher germination percentage than the treated at 68° F. This is what is expected when tubers have already undergone their rest period before being treated, which seems to be true in this experiment since the untreated tubers germinated as rapidly as the treated ones.

The differences between the germination percentage with the treated and untreated lots at 83, and 93° F. are probably not large enough to be significant.

The rate of germination for the 68, and 83° F. beds was about the same, having reached the 50% germination point at about the same time, thus showing no effect of the additional temperature in breaking the rest period. There was not enough sets germinated at 93° F. to have any significant value.

EXPERIMENT II

From Experiment I and from other work which has been done at the Experiment Station here, it has been indicated that a large per cent of decayed tubers result when planted in the soil at a high temperature as is frequently found under conditions of fall-crop production. Table III shows this relationship between high soil temperatures and the per cent decay. In attempt to overcome such large percentages of decay, this study was made to determine the effect of suberization and chemical treatments on seed-piece decay.

As in the first experiment, Oklahoma-grown potatoes were not available; therefore, tubers of Bliss Triumph were purchased from the open market for this experimental work. Neither date nor place of harvest of this seed was known.

Again the electric hotbeds were used for germination as for the first experiment. The hotbeds were set for 80 and 90^{0} F. respectively, but because of the excessively high outside temperatures at this time (June 4), it was impossible to maintain exactly the desired temperatures. This was especially true in the case of two of the beds; however, the center bed remained relatively constant. One of the outer beds which was set at 90^{0} F. ranged from 90 to 95^{0} F. and was occasionally above 95^{0} F.

The following treatments were given the tubers: 1. planted small whole tubers; 2. tubers cut and planted at once; 3. tubers cut and suberized for 7 days; 4. and tubers cut, suberized for 7 days and then dusted with a. Red copper oxide, b. sulphur and lime (half and half by weight), c. Semesan (20% with lime), d. copper carbonate, c. zinc oxide, and f. copper acetate and lime (half and half by weight) g. and the same treatments as just listed with the addition of copper acetate (without lime) on pieces which were freshly cut.

Suberization was accomplished by cutting the tubers and placing them in moist flats, the cut surfaces being placed upward. The flats were covered with moist burlap and were then placed over boxes of damp sand in a cellar where temperature averaged 70^{0} F. In order to retain a humid atmosphere the burlap was moistened each day and placed back over the flats. It should be noted that suberization as referred to in this work implies also wound peridem formation which naturally accompanies or follows suberization.

The seed-piece was rolled in the dry chemicals in treating. All cut surfaces in each experiment were placed downward in planting, in so far as possible.

After treatment, the tubers were planted at temperatures as indicated in Table IV.

Records of emergence of sprouts were taken at definite intervals throughout the germination period.

The results of this study are given in Table IV.

Table IV. Effect of Seed Treatment (Chemicals and Suberization)
(Set June 4, completed July 10, 1937)

Treatment	No. Sets.	Germ. Temp.	Percent Germ.	Percent *Sound	Percent Decay
Suberized sets					
Sulphur and lime	21	90°F.	0	0.0	100.0
Semisan	21	90	0	0.0	100.0
Zinc oxide	21	90	4.8	9.5	85.7
Copper carbonate	21	90	0	0.0	100.0
Red copper oxide	42	80	2.4	19.0	78.6
Untreated	42	80	7.1	19.1	73.8
Total	168		14.3		538.1
Average Per cent			2.4		89.7
Unsuberized sets					
Sulphur and lime	21	90	14.3	4.7	81.0
Semisan	21	90	9.5	0.0	90.5
Zinc oxide	21	90	14.3	9.5	76.2
Copper carbonate	21	90	23.9	0.0	76.2
copper acetate and lime	21	90	42.9	0.0	57.1
Copper acetate	21	90	0.0	0.0	100.0
Untreated	42	90	69.1	19.0	11.9
Total	168		183.4		490.9
Average Per cent			24.9		70.1
Small whole tubers	42	80	0.0	30.9	69.1

*Refers to those sets that did not germinate, but remained sound until the experiment was terminated.

The results in Table IV show that the unsuberized sets gave a much higher per cent germination with less decay than those that were suberized. Since the small whole tubers did not germinate and gave a high per cent of decay also, this is probably explained from the standpoint that both the periderm of the tuber and the suberized layer of cut surfaces inhibit gas exchange as Appel (2) found to be true. Also Appleman (3) found that tubers may be induced to sprout at any time by removing the skins, and since sprouting took place in dry storage much earlier than with those tubers having the skins intact, this could not have been due to water absorption.

This would definitely prove that there is a lack of oxygen available when sets are suberized, or when the original periderm is allowed to remain on the tuber. Steward and Mix (50) found with a volume of air equal to the volume of potatoes, a confinement of 10 to 12 days is sufficient to produce blackheart. Blackheart is a physiological breakdown of the tuber, which is accompanied by discoloration on the inside, and on the outside. However, this discoloration may appear either on the inside or outside or both. As Davis (13) concluded though, blackheart is apparently the result of high respiration, and the failure of the gas exchange to keep pace with the respiration rate. Therefore, the oxygen external to the tuber may be plentiful, and yet as in this experiment, oxygen would be lacking within the tuber tissue.

Respiration is increased by an increase in temperature between 41^{0} F. and 113^{0} F. as found by Bennett and Bartholomew (8), and Braun (9). Therefore, it would be expected, according to David (13) that with a high temperature, resulting in high respiration, and with a limited supply of oxygen available to the tuber tissue, blackheart would be produced. This is what Mann and Joshi (26) in India, found to be true. Tubers in open wire baskets at 97^{O} F. developed blackheart in 6 days.

It would seem logical then to assume that this decay is a result of blackheart injury. Then too Mc-Millan and Meckstroth (28) say that vegetative activity offers resistance to the advance of seed-piece rot. Since the tubers did not germinate they would be more susceptible to rot.

The copper acetate and lime treatment of the seed-piece with unsuberized sets resulted in a higher per cent germination with less decay than the treatments with any of the other chemicals. Even so, it proved to be harmful since the untreated sets gave a higher per cent germination with less decay. As will be noted the copper acetate treatment resulted in 100% decay, showing that the lime in the copper acetate and lime treatment had some desirable effect. The lime probably reduced a toxic effect present with the copper acetate treatment alone. Montemartini (35) found that mild doses of copper acetate increased the rate of suberization, but in this treatment the copper acetate was applied full strength, therefore, suberization probably did not result.

Like suberization, all of the chemical treatments tend to reduce germination and increase the decay. Perhaps their effect was to aid suberization, and thus retard the entrance of oxygen, which would encourage the development of blackheart. This cannot be proved, however, since in every instance except with the red copper oxide treatment, the set was almost completely deteriorated when the experiment was completed.

However, Red copper oxide treatment of suberized sets seemed to retain a continuous protective layer on the outside of the set, even when the set was completely broken down within. Although only 2.4% germinated, 19% remained in a sound condition when this experiment was terminated. It would seem that red copper oxide forms a layer which excludes organisms as completely as suberization without chemical treatment.

This fact further suggests that organisms are not responsible for the decay, but it is due to a physiological breakdown from within the tuber.

To show the relation of temperature to germination and decay Table V is presented, which combines tubers from the several treatments in this experiment.

Table V. Effect of Soil Temperature on Germination and Decay.

Temperature	No. Sets	Ave. % Germination	Ave. % Decay
80^0 F.	204	15.7	60.6
90	210	11.0	86.7
95, plus	204	0.0	92.9

Here again there is a definite trend from the lower to the higher temperature as was found in Table III. Due to the fact that there was a greater fluctuation in germination temperature, and different seed stock used in this experiment, the lower germination for the sets planted is probably accounted for.

EXPERIMENT III

In Experiments I, and II, high soil temperatures seem to be correlated directly with large amounts of decay or breakdown of the sets, but from the data obtained, the decay or breakdown of the seed-piece does not seem to result directly from the activity of decay-producing organisms.

Work which has been done on blackheart (50), (8), (13), and (26) indicates that aeration and high temperatures are factors influencing its production, and it was suspected that blackheart or some similar physiological disorder was responsible for the death of the set at high soil temperatures. Therefore, this study was planned as an attempt to find out how the tubers react under high temperatures and under varying amounts of aeration in the absence of rot-producing organisms.

On July 29, 1937, small whole Bliss Triumph tubers harvested June 10, which had been disinfected with a bichloride of mercury solution (1:1000) for 2 minutes were placed between sterile moist sphagnum moss mats within three 20 cm. petri dishes. The top mats were suspended by a 1/4-inch mesh wire, which allowed some circulation of air within the dish.

The petri dishes containing the tubers were then arranged on shelves within an oven regulated at 98 to 100^0 F. The dish on the top shelf of the chamber, No. 1

was underneath an air vent, and the glass cover to the dish was left off; the dish on the center shelf of the chamber, No. 2 probably did not receive as much air as the top dish since the chamber was small and this dish rested almost directly underneath the other, even though the glass cover was left off also. The third dish was placed on the lower shelf, and the glass cover allowed to remain on. It was removed only at infrequent intervals to add moisture and to examine the tubers. The tubers in the three dishes, therefore, were exposed to varying degrees of aeration. Each day the tubers were inspected for decay.

In Table VI is found the per cent of tubers showing symptoms of decay (blackheart), accordingto intervals of time and by culture dishes.

Table VI. Rate of Blackheart Development at 98 to 100^{0} F. as Indicated by External Symptoms

*Culture No.	No. Used	Per Cent 2 Days	3 Days	6 Days	8 Days	10 Days	12 Days	14 Days	15 Days
1	10	0	0	10	20	30	50	50	50
2	10	0	0	40	50	50	60	70	70
3	10	0	20	60	70	80	80	90	100

* From 1 to 3 the aeration is decreased.

Figures 2 and 3 show the external and internal appearance of typical blackhearted and normal tubers taken at the close of this study.

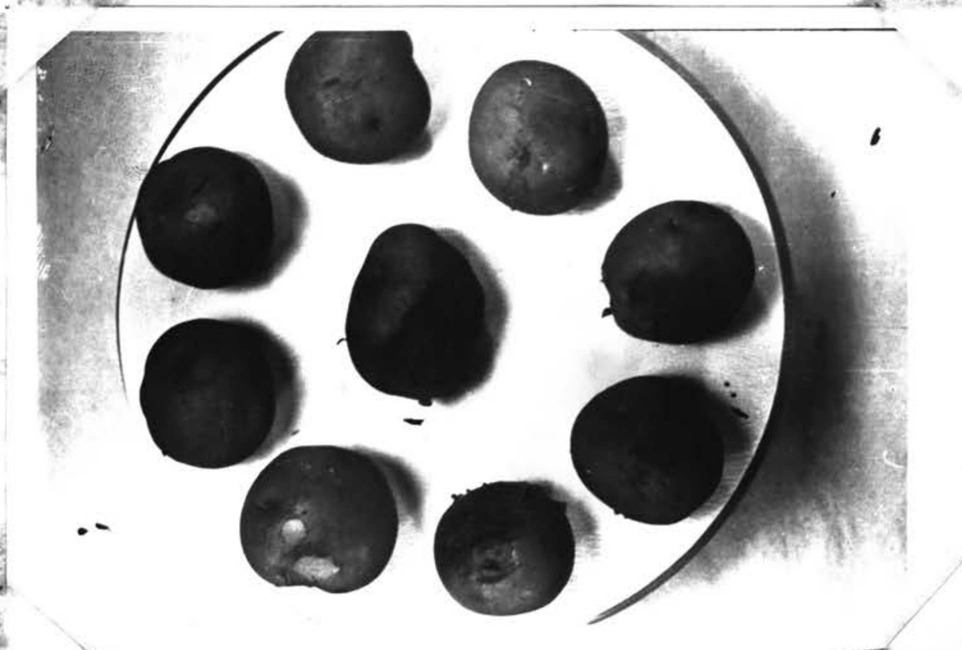

Fig. 2.

Fig. 3.

Normal and blackhearted whole and cut tubers from Experiment III.

The tubers in Culture 1 did not show any blackheart until the sixth day, and only 50% at the end of 15 days. These tubers received, perhaps, the amount of oxygen that they would have received had they been in the open air. This is in agreement with Mann and Joshi's work (26), who found when tubers were heated in the open at 97° F. blackheart occurred in 6 days.

Tubers in Culture 2, which received considerably less exchange of air showed 40% blackhearting at the end of the sixth day, and had blackhearted 70% at the end of the fifteenth day.

The air exchange was practically excluded in Culture 3, and 20% blackheart appeared at the end of the third day. At the end of 15 days 100% of the tubers had blackhearted.

The culture taken from the center of a tuber where the tissue had become softened revealed no pathogenic organisms, although some ordinary soil flora were found. This indicated that only a physiological breakdown was occurring which seemed to be entirely associated with blackhearting.

The data in this experiment indicate that under conditions of high temperature and poor aeration, severe blackhearting, and almost a complete breakdown of the tuber may occur in the absence of pathogenic organisms.

Since absolutely sterile conditions were not maintained in the above work, it was thought the decay noted could not be wholly attributed to physiological disturbances.

Therefore, additional work was planned in an effort to maintain sterile conditions, and to attempt to approximate the aeration which might be expected in the soil.

Small whole Bliss Triumph tubers from the above lot were disinfected with a bichloride of mercury solution, then placed on two sterile moistened mats of excelsior in open sterile pans. The electric incubator in which the pans were placed was disinfected with a 10% formaldehyde solution. Only sterile water was added to the tubers. The temperature was kept at an average of 96^{0} F.

Table VII shows the results of exposing the tubers to very high temperatures with aeration that was considered to be as good or better than that found in a sandy loam soil.

Table VII. Effect of High Temperatures on Decay--Blackheart (Average of 96^{0} F.)

Lot No.	No. Tubers	Days Per cent Decay 12	16	20	26	31	61
1	15	6	13	20	33	40	40
2	15	6	13	40	40	40	40

Under conditions in which this experiment was carried on with adequate aeration and moisture, only 40% of the tubers had shown symptoms of decay or breakdown at the end of two months.

The tubers which had not developed blackheart, or were not discolored, at the high temperatures, were then placed in peat moss in the greenhouse. At the beginning, the greenhouse temperature averaged about 85^{0} F., but due to seasonal changes in the outside temperatures it became lower as time progressed. A total of 62.5% sprouting was secured at the end of 50 days.

The culture of the tubers showing decay still did not indicate pathogenic organisms present, but ordinary soil flora were present.

These data, as that of the previous work, indicate that aeration is an important factor at high temperatures, and that so long as tubers appear in a sound condition some potentiality for sprouting is retained. However, excessively high temperatures for long periods of time seem to induce a second rest period, or prolong the rest period. This is interesting, and seems to warrant further investigation. Loomis (24) suggests a secondary dormancy might be induced by planting seed, which has been chemically treated to break the dormant period, in a soil where the moisture content is low. So far as is known, however, no one observed a secondary rest period in potato tubers resulting from prolonged exposure to high temperatures.

EXPERIMENT IV

Since treating the tubers with ethylene chlorhydrin in these studies, had not caused the tubers to germinate more rapidly, or had not resulted in higher per cent germination, and more decay was prevalent in treated seed, the concentration of ethylene chlorhydrin being used was thought to be too strong.

Also cut, unsuberized sets germinated a great deal better than the whole tubers or suberized sets under laboratory conditions. It was desired to check these results under field conditions, as well as the results with the tubers treated with ethylene chlorhydrin, and then dusted with Red Copper oxide which had apparently provided good external protection for the seed-piece. Therefore, this investigation was made to determine the effect of concentration of ethylene chlorhydrin on germination at high temperatures; to compare cut sets with whole tubers; and to check on results with suberization, and treatment of the seed pieces with red copper oxide.

Bliss Triumph Irish potatoes, harvested June 10, 1937, from the station farm were used for this experiment. The potatoes were treated with 0.5, 1.0, 1.5, and 2.0 cc. of ethylene chlorhydrin per liter of air space. Large air-tight cans were used in which the ethylene chlorhydrin was introduced by being absorbed in cheese cloth and suspended at the top of the can. As in the other experiments a 24-hour treatment was given.

Suberization of the cut sets was accomplished in the same manner as described in Experiment II, except that the temperature of the cellar remained at about 84^0 F. and some difficulty was experienced in maintaining a moist atmosphere. All cut sets consisted of approximately 1-ounce pieces.

The sets were planted in the field on July 6 in plots of 20 sets each, with three replicates, except in the case of the suberized lots, which were planted in replicates of 15 sets each.

Records were secured, beginning July 26, and ending August 13, when emergence had ceased.

A sample of the daily mean soil and air temperatures as recorded by a thermograph is given in Table VIII. Also the maximum daily soil and air temperatures are given, showing the differences between them. The daily mean temperature was determined by planimeter readings taken from daily temperature charts.

Table VIII. Soil and Air Temperatures from July 8-18

	Daily Mean			Maximum		
Date	Soil	Air	Dif.	Soil	Air	Dif.
July 8	87.5^0 F.			96^{0}F.	102^{0}F.	6^{0}F.
9	80.5	92.5^0 F.	12.0^0 F.	92	98	6
10	74.3	80.0	5.7	78	84	6
11	77.3	85.0	7.7	84	90	6
12	79.8	87.5	7.7	88	94	6
13	83.8	90.0	6.2	96	106	10
14	87.2	92.0	4.8	96	102	6
15	85.6	89.5	7.9	93	100	8
16	87.0	87.5	0.5	98	98	0
17	83.5	80.0	3.5	92	96	4
18	89.0	90.8	1.8	96	102	6
				98	98	0

It is noted in Table IX that as an average a very low germination resulted from tubers of the various treatments. The reason for this low germination is found in the temperature data presented in the preceding Table (VIII). It will be noted that the daily soil means varied from 75 to 89^0 F. with maximum soil temperatures quite consistently above 90^0 F. For 2 to 3 weeks following the period covered by the data in Table VIII, these high temperatures continued.

It is interesting to note that a rather consistent difference was found between the soil and air temperatures. Considering the data on maximum temperatures this difference appears to be about 6^0 F. A more extensive study of this relationship should make it possible to approximate soil temperatures from air temperature data. This would be desirable since soil temperature data are not generally available. The writer realizes, of course, that factors such as soil type and color, soil moisture, atmospheric humidity, light intensity, and other factors would probably enter into this relationship between air and soil temperatures.

Table IX shows the results of treating tubers with various concentrations of ethylene chlorhydrin, of cutting the tuber before planting, of suberization after treatment with ethylene chlorhydrin, and treatment with red copper oxide after suberization.

Table IX. A Study of Concentrations of Ethylene Chlorhydrin, Wounding, Chemical Treatment of the Seed Piece, and Suberization. (Data Secured under Field Conditions.)

Treatment	No. Sets.	No. Germinated	% Germinated
Whole sets			
1.5 cc.	80	8	10.0
1.0	80	0	0.0
1.5	80	6	7.5
2.0	80	4	5.0
Untreated	80	9	11.3
Total	400		33.8
Average Per cent			6.8
Cut Sets			
0.5 cc.	80	5	6.3
1.0	80	4	5.0
1.5	80	8	10.0
2.0	80	6	7.5
Untreated	80	7	8.8
Total	400		37.6
Average Per cent			7.5

Cont'd

Treatment	No. Sets	No. Germinated	% Germinated
1.0 cc. and suberized	60	22	36.7
Suberized and treated with Red Copper oxide	60	20	33.3

According to the data presented in Table IX, there are no consistent differences in germination results between the tubers treated with various concentrations of ethylene chlorhydrin. Contrary to the data obtained in Experiment II, the cut sets did not germinate significantly different from those tubers planted whole. However, this is not conclusive proof that the cut sets will not germinate more rapidly with a higher per cent germination as was found in the laboratory, and the writer feels that this should be a point for further experimentation.

In this experiment with ethylene chlorhydrin treatment (1 cc. per liter of air space) sets suberized gave a higher per cent germination than the unsuberized. Also the untreated suberized sets, treated with red copper oxide gave about the same per cent germination as the treated, suberized sets. This would indicate that the treatment with 1 cc. of ethylene chlorhydrin had very little effect on the germination, and that treatment with red copper oxide was also ineffective.

EXPERIMENT V

Under the conditions of these experiments high temperatures seem to be associated directly with seed-piece decay and ethylene chlorhydrin treatment for breaking the rest period tends to be injurious, that is, the decay of treated sets is greater than that of untreated sets.

So far, cutting the tubers for planting seems to be the best method of abbreviating the rest when potatoes are planted under high soil temperatures, and since the copper acetate and lime treatment of cut sets resulted in almost as high a per cent germination as with untreated sets, it seemed worthwhile to repeat these experiments.

Miller (34) observed a maximum rate of respiration 50 to 60 hours after treatment, then a gradual decrease until a value approached corresponding to that of untreated tubers in about a week after treatment. Since high respiration is associated with blackhearting of the tubers, to determine the effect of allowing time after treatment with ethylene chlorhydrin for the respiration to become normal before germinating at high temperatures apparently offered a method of overcoming the effects of high respiration.

In an effort to devise some method whereby the rest period may be abbreviated to the maximum extent, with a minimum of decay, this experiment was planned to determine the effect of allowing time after treatment with ethylene chlorhydrin for the respiration to become normal before germinating at high temperatures; to determine the germination response of ethylene chlorhydrin treated tubers, cut and dusted with copper acetate and lime to prevent seed-piece decay; and to compare the germination response of ethylene chlorhydrin treated whole and cut tubers.

Bliss Triumph Irish potatoes from Muskogee, Oklahoma, harvested November 4, 1937, were treated December 8, at 80^0 F. with 1 cc. of ethylene chlorhydrin per liter of air space for 24 hours in the same manner as for Experiment IV. After airing for 24 hours, half of the tubers were cut into approximately one-ounce pieces, and half were left whole. The tubers were then set in flats within an electrically heated chamber with thermostatic control where the temperature ranged from 93 to 96^0 F. for germination. The soil in the flats in which the sets were germinated was composed of one-third peat moss, and two thirds sand.

A second lot of Bliss Triumph Irish potatoes from the Experiment station, harvested November 16, 1937, were treated with the above lot of tubers. Instead of removing the tubers after airing for 24 hours as was done with the other lot, these tubers were allowed to remain at 80^0 F. for 6 days after treatment. After which a portion of the tubers was left whole, and a portion cut. One lot of the cut tubers was rolled in a powder composed of one-half copper acetate and one-half lime. The tubers were planted in a soil of half peat and half sand contained in flats. These flats were then placed in chambers at 93 to 96^{0} F. Fans were placed at the bottoms of the chambers, and a favorable humidity was maintained by the evaporation from a free water surface.

At frequent intervals germination records were secured. As the sprouts emerged, the sets were removed from the flats. The earliest planting was made January 9, and the records were completed February 19.

Table X shows the effect of cutting the tubers before planting, the effect of holding the tubers for a short period of time before setting at high temperatures to germinate, and the effect of dusting the seed-piece with copper acetate and lime.

Table X. Effect of Delayed Planting after Treatment with Ethylene Chlorhydrin, of Copper Acetate and Lime Treatment of Seed-Piece, and of cut vs. whole sets. (Germinated 93-96^{0} F.)

Treatment	No. Sets	% Germination	% Decay	Rate of Germ. (Days to 50%)
Whole Tubers				
Tr., Pl. Imed.	72	26.4	73.6	55
" " in 6 da.	48	60.3	39.7	49
Untreated Pl. in 6 da.	48	56.7	43.3	62
Total	168	143.4	156.6	166
Average %		47.8	52.2	55

Cont'd

Treatment	No. Sets	% Germination	% Decay	Rate of Germ (Days to 50%)
Cut Sets				
Tr., Pl. Imed.	72	55.6	44.4	46
" "in 6 da.	78	64.1	35.9	42
Untreated Pl. in 6 da.	60	91.7	8.3	46
Total	270	211.4	88.6	134
Average %		70.5	29.5	45
Tr., dusted Copper Acetate and lime Pl. in 6 da.	60	88.3	11.7	42

As presented in Table X, cutting the sets, again increased the germination percentage and decreased the decay over tubers planted whole. The rest period is also abbreviated on an average of 11 days with the cut sets.

Delaying planting for 6 days more than doubled the per cent germination when whole tubers were used, while the difference was not so great with the cut sets. This is what is expected. With tubers treated with ethylene chlorhydrin the respiration is increased. With the whole tubers at high temperatures there is a lack of oxygen within the tissue of the tuber because of slow oxygen penetration, which is not true of the cut sets.

Treating the cut sets with ethylene chlorhydrin, and then dusting with copper acetate and lime resulted in almost as high a germination percentage as with the untreated cut sets, but was considerably better than treating the tubers and planting immediately, or holding at the lower temperature for 6 days.

This treatment certainly appears promising, since this is the highest germination received from ethylene chlorhydrin treated sets. However, the rest period was not abbreviated to any extent.

If tubers are planted whole, it would be desirable to hold the tubers following treatment with ethylene chlorhydrin, for about 6 days, or until the high respiration is past before planting in the soil with a high temperature. When the tubers are cut before planting, delaying planting does not seem so important.

EXPERIMENT VI

As in Experiment I, the purposes of this experiment are to determine the effect of ethylene chlorhydrin treatment and length and temperature of storage after treatment. However, in this experiment higher storage temperatures are used with a lesser concentration of ethylene chlorhydrin and it was thought that the rate of shrinkage of the tubers in storage after treatment might be valuable. Therefore, this additional investigation was added.

Bliss Triumph Irish potatoes harvested at the Experimental farm November 4, 1937, were treated with 1 cc. of ethylene chlorhydrin per liter of air space for 24 hours in the same manner as for Experiment IV and V, on November 29.

After airing for 24 hours the tubers were then stored at 85, 90, and 95^{0} F. in the same chambers as used in Experiment V, for 5, 12, and 21-day periods, respectively. The tubers were weighed at the beginning, then again at definite intervals during the storage period.

At the end of each storage interval, tubers from each of the chambers were removed, and cut into 1-ounce pieces for planting in flats of soil composed of one-third peat moss, and two-thirds sand. The flats were placed in the greenhouse with an average temperature of 70^{0} F.

In cutting the tubers for planting, at the end of the first interval a great deal of blackheart was evident, therefore, a record was kept of the number of sets showing blackheart. Blackheart was determined by observing whether or not the pieces turned pink on standing or were already blackened. It should be understood that the cut surface of newly blackhearted tubers on being exposed to the air first develops a pink color which subsequently changes to black. The seed-pieces were divided into classes-severely blackhearted, medium, slight, and no blackheart--within each lot for planting.

Germination records were taken as the sprouts appeared above the soil. Table XI indicates the amount and degree of blackheart at the three storage temperatures for the three intervals.

Table XI. Blackheart after Storage at 95, 90 and 85° F. (Per cent of Total Sets of Ethylene Chlorhydrin Treated Tubers)

Storage Temp.	Degree of Blackhearting											*Index of Blackheart
	None		Slight		Medium		Severe		Total		%	
	No.	%	No.	%	No.	%	No.	%	No.	%	None	
Treated												
95° F.	10	10.8	8	8.6	15	16.1	60	64.5	93	88.2	10.8	3.44
90	35	48.6	5	6.9	11	15.3	21	29.1	72	51.4	48.6	2.94
85	35	47.3	14	18.9	5	6.8	20	27.0	74	52.7	47.3	2.64
Control												
95	27	81.8	4	12.2	—	—	—	—	31	12.2	81.8	
90	25	100.0	—	—	—	—	—	—	25	0.0	100.0	
85	20	100.0	—	—	—	—	—	—	20	0.0	100.0	

* Average degree of blackhearting calculated for arbitrarily assigned values with the observed degrees of blackhearting, weighted as follows: No blackhearting, 1; slight blackhearting, 5; medium blackhearting, 10; severe blackhearting, 20.

With treated tubers there is a definite correlation between very high storage temperatures and the percentage of blackheart as can be seen from Table XI which is in agreement with other work done (26), and (13). The untreated tubers did not blackheart at the lower temperatures, but at 95^0 F. 12.2% blackhearted.

According to the figures in Table XI, 85 and 90^0 F. seem to be about equal in value, but when the figures are given a weighted value, as should be done since the degree of blackheart is directly related to the germination value, there is considerable difference. The index figure for 90^0 F. is 2.94 as compared to 2.64 for 85^0 F. These figures as compared to 3.44 for 95^0 F. show the direct relationship between the three temperatures.

Under conditions of this experiment high respiration resulting from treating the tubers with ethylene chlorhydrin is apparently responsible for the high per cent of blackheart occurring in storage.

The blackheart data for the various storage temperatures (95-90-85) were combined and presented according to storage intervals in Table XII.

Table XII. Effect of Length of Storage on Production of Blackheart.
(Tubers Treated with Ethylene Chlorhydrin)

Storage Interval	Average Per cent of Tubers: No Blackheart	Average Per cent of Tubers: Total Blackheart
Treated tubers		
5-day	38.7	60.9
12 "	26.5	73.5
21 "	44.6	55.3
Untreated tubers		
5-day	86.6	13.3
12 "	* ___	___
21 "	97.1	2.9

* No untreated tubers removed at this interval.

As in Experiment I, the treated tubers in the 21-day storage results in less blackheart, being followed closely by 5-day, and then the 12-day period. This same trend is shown for untreated tubers also.

Table XIII shows the weight loss of treated and untreated tubers during the 21-day storage period at 85, 90, and 95^{0} F.

Table XIII. Loss in Weight of Both Treated and Untreated Tubers During Storage for 21 days at 85, 90, and 95° F.

% cumulative loss	Orig. Wt.	3 days	5 days	8 days	12 days	16 days	19 days	21 days
		Weight in Pounds						
Treated								
95° F.	17.1	2	5	8	11	16	20	22
90	14.8	2	4	6	8	11	14	14
85	12.9	2	4	6	8	11	12	19
Untreated								
95	5.5	2	5	7	9	11	13	13
90	4.8	2	4	6	6	8	9	11
85	3.9	2	4	5	5	5	7	11

The weight loss in storage is much greater for ethylene chlorhydrin treated tubers than untreated ones, and the loss increases with the increasing temperature, according to Table XIII.

This would indicate that the greater loss in weight might be associated with high respiration since ethylene chlorhydrin treatment and high temperatures increase the respiration rate of the tuber. However, Smith 45 says the loss in weight due to respiration in storage is very small compared to the loss caused by evaporation of water. In this particular experiment the losses seemed to have been due to the complete breakdown of a large number of tubers. The severely blackhearted tubers broke down and shriveled up, while the ones free from blackheart did not shrivel.

Table XIV brings out the relationship between the degree of blackhearting and the resulting germination percentage of ethylene chlorhydrin treated and untreated sets.

Table XIV. Effect of Degree of Blackhearting of ethylene chlorhydrin treated sets on subsequent germination.

Storage Temperature	No blackheart No. Sets	No blackheart % Germ.	Slight No. Sets	Slight % Germ.	Medium No. Sets	Medium % Germ.	Severe No. Sets	Severe % Germ.
Treated								
95°F.	26	50	23	8.7	39	0.0	42	0.0
90	88	80.2	27	25.9	22	4.6	22	0.0
85	86	79.6	63	20.6	5	0.0	23	0.0
Average %		76.0		19.5		1.2		0.0
Untreated								
95	64	92.2	12	6.0	*			
90	74	97.3						
85	64	100.0						
Average %		96.5		50.0				

* None of the untreated tubers developed medium or severe blackheart.

The data from Table XIV indicate there is a direct correlation between the degree of blackhearting and subsequent germination. The untreated tubers gave a much higher average percentage germination with much less blackheart than the treated.

Steward and Mix (50) conclude that if tubers are sound and normal in appearance it is unlikely they have been injured for seed purposes by storage conditions. From the results in Table XIV this would hardly be entirely true. To be absolutely sure, the tubers should be cut into pieces.

If the tubers have been treated with ethylene chlorhydrin and there is any possibility that blackheart may have occurred, it would be desirable to inspect the tubers thoroughly. Even though the tubers may look perfectly sound from the outside, cutting and exposing to the air for a few minutes may disclose pink areas. These areas may cover a large portion of the set, or only a small portion.

Table XV is the result of data from the different storage temperatures combined to present the effect of length of storage.

Table XV. Effect of Length of Storage after Treatment with Ethylene Chlorhydrin on Percentage Germination

Storage Interval	No. Sets	% Germinated
Treated		
5-day	180	31.6
12 "	179	29.5
21 "	117	44.6
Untreated		
5-day	62	91.6
21 "	158	92.3

With treated tubers the storage interval of 21 days resulted in a higher percentage germination, being followed by the 5-day period, and the 12-day period respectively. With the untreated tubers there is very little difference between the germination of tubers stored for 5- and 21-day periods. However, the 21-day period again gave the higher germination percentage.

The results of storage temperature on germination are shown in Table XVI.

Table XVI. The Relationship of Treatment with Ethylene Chlorhydrin and Storage Temperatures on Rate and Per cent Germination

Storage Temperature	No. Sets	% Germination	Days to 50% germination
Treated			
95° F.	122	14.6	22
90	159	50.7	21
85	199	40.1	26
Total	480	105.4	79
Average		35.1	26.3
Untreated			
95° F.	82	78.0	54
90	74	98.0	63
85	64	100.0	56
Total	220	276	173
Average		92.0	57.6

Of the untreated tubers 78% germinated at 95 storage, 98% at 90, and 100% at the 85° F. storage. Under the conditions of this experiment at 90° F. the treated tubers germinated 10% more than the tubers stored at 85° F. Here again the 95° F. storage resulted in the lowest germination percentage--14.6%. As in Table XIV with storage, there is not such a great difference between the germination at 85 and 90° F., but the additional 5° results in a considerably greater loss, especially is this true with tubers treated with ethylene chlorhydrin.

Fig. 4. Classification of degree of blackheart as used in Experiment VI.

SUMMARY AND CONCLUSIONS

1. The optimum concentration of ethylene chlorhydrin for the vapor treatment of whole Bliss Triumph Irish potato tubers will vary with the temperature of the atmosphere while treating, and the storage or germination temperature.

2. Soil temperature is an important factor in regard to the germination and decay of potato tubers or sets. Germination at high temperatures was usually reduced markedly, and decay of the sets was increased.

Treating the sets with chemicals in an effort to prevent this decay proved to be mostly ineffective. Certain of these chemicals, notably, red copper-oxide preserved the exterior of the sets, but a break-down occurred in the internal tissues.

High soil or storage temperatures, especially when following ethylene chlorhydrin treatment caused considerable break-down of the tubers or sets. This break-down was presumably associated with blackhearting, and took place independent of decay-producing organisms. Blackhearting was the result of the high rate of respiration in the sets or tubers. The high respiratory rate was induced by high temperatures, or by treatment with ethylene chlorhydrin or by the combined effects of both high temperature and treatment with ethylene chlorhydrin.

Blackhearted tubers gave a very low germination percentage, the germination being inversely proportional to the severity of the blackheart injury.

Briefly stated this study indicates that the seed-piece "decay" as prevalent in fall-crop potato production is initially a physiological break-down of the seed-piece which is akin to or associated with blackheart. There is no doubt that decay organisms complete the disintegration of the seed after the physiological break-down of the living tissue takes place.

3. Storage of seed potatoes at a moderate temperature (80° F.) for some time after treating with ethylene chlorhydrin seems to be desirable for two reasons: First, to elinimate tubers that might have been injured by treating, and secondly, to allow for the restoration of the normal rate of respiration.

4. Newly cut sets sprouted more quickly with a greater germination percentage than whole tubers or sets suberized before planting when planted in the soil at a high temperature. This seems to be due to the greater permeability of the unsuberized cut surface to oxygen.

5. The cutting of the tubers proved to be a mild dormancy-breaking treatment and was additive to the

effects of ethylene chlorhydrin treatment. Sets cut from ethylene chlorhydrin treated tubers germinated on an average of 11 days earlier than the uncut tubers.

6. The weight loss of tubers in storage varies with the temperature of storage, and with ethylene chlorhydrin treated and untreated tubers. A temperature of 95° F. causes a much greater loss in storage than 85, and 90° F. with ethylene chlorhydrin treated tubers. The difference is not so great with untreated tubers. However, the loss of the treated tubers is considerably greater than the untreated ones.

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