FURTHER EXPERIMENTS IN THE DEVELOPMENT OF ENGINEERING METHODS FOR THE CONTROL OF LOOSE SMUT IN WHEAT

Thesis for the Degree of M. S.

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George Eli Cheklich

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This is to certify that the

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D. E. Wiant

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FURTHER EXPERIMENTS IN THE DEVELOPMENT OF ENGINEERING METHODS FOR THE CONTROL OF LOOSE SMUT IN WHEAT

by

George Eli Cheklich

An Abstract

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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FURTHER EXPERIMENTS IN THE DEVELOPMENT OF ENGINEERING METHODS FOR THE CONTROL OF LOOSE SMUT IN WHEAT

Loose smut of wheat causes an estimated total annual loss to the farmers of the United States, of more than eleven million bushels. Since loose smut is an internally seed-borne fungus, it is necessary to employ a treatment which will penetrate the wheat seed and kill the loose smut fungus, without affecting the wheat germ. At present, the only treatments known to be effective in the control of this disease are the various hot water treatments. Hot water treatments are difficult and tedious to apply and require close temperature control. The main objection to the hot water treatments is that the seed is wetted during treatment.

Because of the aforementioned disadvantages of the hot water treatments, there appeared to be a need for a dry treatment. In previous investigations infected seed was treated with infrared radiation and dielectric heat. Infrared radiation was found to be the more practicable treatment.

This study is in part, a further investigation of the infrared treatment. An infrared heat lamp was used as a source of infrared radiation. Results of field tests with infrared treated seed indicate that the infrared treatment may be effective in the control of this disease. However, because of a number of contributing factors, considerable difficulty was encountered in reproducing the infrared treatments. These factors are: (1) influence of air currents, (2) uncontrollable exposure of the wheat embryo during treatment, and (3) variations in atmospheric absorption of infrared radiation.

Subsequently, the effects of treating wheat in an electric oven were investigated. A number of samples of wheat were oven treated and planted in the greenhouse. Results from these tests indicate a trend of decreasing loose smut incidence in those samples treated above 98°C. for a period of more than thirty minutes. An investigation of this treatment using a much larger number of plants is necessary to determine the optimal conditions under which loose smut of wheat can be controlled.

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INTRODUCTION

Loose smut is one of the commonly known destructive diseases of wheat. According to estimates compiled by the Bureau of Plant Industry, the average annual loss to farmers of the United States resulting from this disease is more than 11,000,000 bushels. While this loss is not as great as that resulting from other diseases of wheat, it is a considerable amount and certainly warrants some attention.

Loose smut infected plants appear to be normal during the growing season. It is only during the flowering stage of the growing cycle that loose smut can be detected. At this time, the infected heads appear as a black mass of smut spores instead of normal heads. The infestation has been known to be as high as 40 percent. Usually all the heads from a diseased plant are infected. The yield would therefore be lowered because of a reduction in the number of normal plants.

Because loose smut is an internally borne fungus, it cannot be controlled by treating with surface disinfectants as can other smuts of wheat. It can be controlled only by a treatment which in some way penetrates the wheat kernel and kills the loose smut fungus without affecting the embryo. Hot-water treatments are the only generally recommended preventive measures at present. These treatments are not being practiced extensively because they are tedious and difficult to apply under usual farm conditions. They also require close temperature control, and wet the seed during treatment. Generally speaking, they reduce germination, retard emergence and decrease yield. These treatments have been carried out satisfactorily in some areas on a community basis under the supervision of an agricultural specialist.

There seems to be a tendency on the part of the grower to underestimate the importance of losses from loose smut. There are two factors responsible for this. First, loose smut is inconspicuous at harvest time and therefore cannot be appreciated by the grower. Secondly, the milling quality of the wheat is not affected by the presence of loose smut as it is by the presence of other smuts of wheat. Therefore, the losses from loose smut are field losses and not market losses.

This study is a continuation of earlier research on the development of a dry heat treatment for the control of loose smut in wheat. Its primary purpose was to develop a method which would lend itself to large scale treatment of wheat.

REVIEW OF LITERATURE

The Nature of Loose Smut

Loose smut (Ustilago Tritici), is one of the many diseases which affect wheat. It differs from other smuts of wheat in that its presence can be detected only during the flowering stage of the growing cycle. The smut infected heads emerge from the boot slightly earlier than the normal heads. They appear as black masses of spores instead of an otherwise healthy head of wheat, which upon drying, becomes powdery and sooty. Sometimes only the lower part of the head is destroyed leaving the upper part of the head unaffected. But usually, the whole head is infected, and the glumes and grain completely destroyed.

These black masses of spores are surrounded by a thin membrane which consists of the infected glumes. This membrane soon ruptures and as the smut spores dry they are spread about the field by the wind, insects and other agencies. The greatest number of black heads in an infected field are apparent when the wheat is in full bloom. As these countless numbers of spores are scattered and carried about the field, they become lodged between the glumes of the healthy heads. Inoculation occurs when one or more of these spores happen to fall on the ovary or stigma which is exposed between the glumes when the healthy heads are in bloom. Within a few days all the smut spores are either blown, carried, or washed from the diseased heads leaving only the naked rachises of the spikes.

The spores soon germinate and the germ tubes produce a mycelium within the developing seed. This smut mycelium soon stops growing and remains dormant in the wheat kernel. When the infected seed is planted and growth begins, the dormant mycelium revives and begins to grow along with the wheat.

When the wheat reaches the flowering stage, the black masses of spores appear, and the life cycle is concluded. The development of loose smut at several different stages is shown in Figure 1.

Since loose smut is an internally borne fungus, it can be transmitted only during the flowering stage of the growing cycle. When the plant is growing, it is impossible to distinguish between an infected plant and a healthy plant by observation. Likewise, after harvest the affected seeds appear to be normal. There is no difference in color, size or shape between the infected and uninfected seed. The structure of the wheat berry appears in Figure 2.

It has been found by Tapke (28) that wheat plants infected with loose smut will winter-kill more easily than uninfected plants. This, of course, is desirable but the yield may be reduced markedly if the planting rate is not adjusted to compensate for this loss.

Rapid Method for Detection of Loose Smut Mycelium.

Popp (22) reports the following rapid method for detecting the presence of loose smut mycelium in seeds and seedlings. "Before seed embryos could be prepared for examination, it was necessary to separate them from the endosperm and pericarp. Kernels were macerated for 48 hours in a 10 percent solution of potassium hydroxide at room temperature. During maceration, the endosperm and embryo became swollen and usually ruptured the pericarp. The solution and macerated seed were poured into a 10-mesh sieve, through which the embryos were strained into a beaker with the aid of a rinse spray. The solution was then poured off and replaced with a 10 percent solution of potassium hydroxide, and in it the embryos were boiled for about one minute each time to leach out most of the potassium hydroxide.

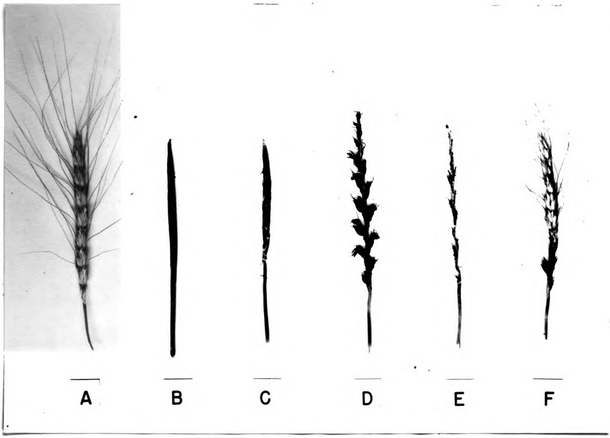

Figure 1. Wheat heads showing appearance and development of loose smut.

A. Normal head.

B. Smutted head in the boot.

C. Smutted head as it emerges.

D. Stage of spore distribution.

E. Rachis after spores are gone.

F. Partially normal and partially infected head.

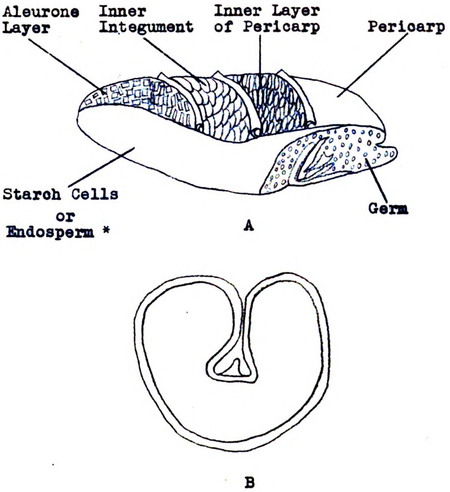

Figure 2. Structure of the wheat berry.

A - Wheat berry cut through at the crease.

B - Cross section of the wheat berry.

* The loose smut mycelium is believed to lie dormant in the endosperm and/or in the wheat germ.

To facilitate the detection of mycelium, the embryos were boiled for about four minutes in a staining solution.* The treated embryos were mounted in rows on glass slides and slightly flattened under a cover glass for examination under the microscope. The mounting medium was a solution of one part glycerin and two parts distilled water. During treatment, the embryo tissue became light blue and translucent. The mycelium was more darkly stained and could be easily recognized in the semitransparent host tissue. An embryo was considered to be infected if smut mycelium was found in any part of it."

In the detection of loose smut mycelium in seedlings, only a portion of each seedling was used. This included the crown node, about 1/8 inch of the sub-crown internode, and 3/8 inch of the plumule. These were excised for examination of the growing point after the tip of the second leaf had made its appearance. The excised pieces were boiled in a 10 percent solution of potassium hydroxide for about five minutes or until the tissue became semitransparent. The seedling pieces were then washed, stained, mounted, and examined in the same manner as the embryos.

A modification of this method was employed in the detection of loose smut mycelium in wheat samples originating from the 1950 and 1951 crops of spring wheat variety Illinois 1-128 which had shown heavy infection in the field. Results of these tests appear in Table 1.**

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* Lactic acid 12.5 cc.; phenol (at 45-50°C.), 12.5 cc.; glycerin, 12.5 cc.; distilled water 62.5 cc.; and Poirrier's blue (cotton blue), 0.01 gm. In making up the solution, the cotton blue was dissolved in lactic acid and water, and the other ingredients were then added.

** Acknowledgment is due to Mustapha Zeidan, graduate student in the Department of Botany and Plant Pathology, for carrying out this work.

Table 1. Results of detection of loose smut mycelium in the seedlings of spring wheat Illinois 1-128.

Crop	Number of Slides	Number of Seedlings		Percent
		Total	Infected	
1950	14	66	11	16.5
1951	10	48	14	29

The usual and most reliable method of estimating loose smut infection in wheat plants is to plant the seed and record the percentage of smutted plants. Field tests, however, are time-consuming and allow experimentation only at certain times of the year. For this reason greenhouse culture of a suitable variety was considered to be of great importance. The aforementioned variety, Illinois 1-128, was found particularly suited for this purpose because of the high incidence of spontaneous smut infection and short growing period. When these desirable properties became apparent, earlier attempts to utilize Popp's method routinely were abandoned.

Methods of Treatment Previously Used

A number of different methods have been used in the control of loose smut in wheat. They are (1) the selection of large kernels, (2) the use of seed more than one year old, (3) the removal of smutted plants from the field, (4) the use of clean seed, (5) the treatment of seed with hot water, (6) the selection of resistant varieties and strains, (7) the treatment of seed with infrared radiation and dielectric heating. Of these control methods which have been tried, the use of resistant varieties and strains, which are otherwise desirable, and treatment of the seed with hot water have proven to be most effective.

Use of Resistant Varieties.

Because of the technical difficulties involved in other control methods, it would seem that the use of resistant varieties offers the most practical means of controlling this disease. A number of varieties have been reported resistant by some and susceptible by others. Only a few varieties have been consistently reported as showing any marked degree of resistance. In common wheats the resistance ranged from high susceptibility to apparent immunity. It has been suggested that apparent resistance in varieties may be due simply to escape of the disease by virtue of a relatively cleistogamous habit of blooming, to an anthesis of short duration, or to both. However, tests conducted by Tapke (30) indicate that this was not the case but that it was due to something more fundamental in its constitution.

Some varieties are better adapted to certain growing conditions than others. This is a factor which must be considered before selection of a variety is made.

Relative Humidity During Blooming Period.

Loose smut rarely occurs in the Pacific Coast states. It is believed that the low relative humidity which generally prevails there during the flowering period might play an important role in preventing infection (31). It is quite prevalent in the eastern or more humid areas of the United States. The loose smut fungus is very much dependent on moisture for its existence. Perhaps the spores are dehydrated to the extent that they will not germinate when they reach the ovary, in the low relative humidity regions.

Three varieties which are grown in one or more of the Pacific Coast states and rarely produce loose smut there, were inoculated under humid conditions in a greenhouse at the Arlington Experiment Farm, Rosslyn, Virginia (31). The resulting seed produced from 91 to 98 percent smutted plants. The percentage of smutted plants was considerably less when they were subjected to a low relative humidity after inoculation.

Hot Water Treatments

Modified Water Bath Treatment.

Tapke (28) reports the following treatment which is a modification of an earlier hot water treatment. In the modified hot water treatment, the wheat is placed in a porous container, usually a burlap sack. The sacks are only half filled because soaking causes the wheat to swell considerably. The sacks are then tied at the top.

The wheat is then presoaked for 4 to 6 hours in unheated water. It is then dipped momentarily in water heated to 49°C. to warm the seed and then soaked for 10 minutes in water maintained at 54°C. Finally, it is either dipped in cold water or spread in a thin layer without dipping in cold water and allowed to dry and cool.

Single Bath Treatment.

In the single bath hot water treatment, the initial 4 - 6 hour period of presoaking is omitted. The seed is soaked for one hour and fifty minutes in water at a temperature of 48°C. or for one hour and thirty-five minutes in water at a temperature of 49°C. The seed is then spread in a thin layer and allowed to cool and dry. During the presoaking period in the modified hot water treatment and throughout the single bath treatment, the sacks should lie on their sides. They should be turned over occasionally to prevent caking of the swelling wheat.

Steam Bath Treatment.

Tapke (28) reports the following steam bath treatments. The wheat is first soaked for four hours in unheated water. It is then placed in a small forced air drier which is equipped to circulate a saturated atmosphere of constant temperature. Constant temperature of the saturated air is maintained by using steam of temperatures between 26° and 48°C. The length of treatment varies from one to five hours depending on the temperature used. The wheat is then dried by forced air.

Some of the steam treatments were effective in controlling loose smut without material injury to germination or reduction of yield. However, the application of steam treatments to large quantities of wheat would involve difficulties not encountered in the smaller experiments.

Limitations of the Hot Water Treatments.

The hot water treatments are difficult and tedious to apply. They involve long periods of time for treatment. Also, during hot water treatments the wheat becomes wet and swollen. This introduces the problem of drying the wheat. This procedure is rather tedious and expensive in that it involves time, space, labor, and some risk of loss of seed wheat through sprouting or freezing. The drying process could be omitted if the seed is sowed as soon as its surface is dry. Seed in this condition would still contain enough moisture to germinate in a dry soil. However, if the soil remains dry after germination, some of the seedlings may die and the stand may be severely injured. If the seed is planted when swollen, it is difficult to adjust the rate of seeding and a thin stand may result.

The effectiveness of these three treatments is dependent upon very close temperature control. If the temperature is not closely controlled, the damage resulting from the treatment may be even greater than that resulting from the loose smut infection. The application of these treatments involves the maintenance of a constant temperature for relatively long periods of time. Special equipment is also required which makes the application of these treatments impractical for the individual farmer.

The effects of these treatments on germination are dependent on the physical condition of the seed coat. Mechanical threshing usually results in some broken, cracked, or scratched seeds. When the seed coat is broken at definite locations over the endosperm, the germination is somewhat retarded. When the seed coat is broken over the embryo, the treatment reduces germination markedly. These treatments will serve to screen the defective seeds from the healthy seeds. However, if the percentage of defective seeds is quite high, there will be a marked loss in germination. Germination tests of the treated seed should be made prior to planting. The planting rate can then be adjusted to counteract this loss of germination.

According to Tapke (28), when the planting rate was adjusted so that the number of viable seeds was the same for the treated and untreated wheat, the untreated seed outyielded the treated seed. This would indicate that the effect is not confined to germination but may extend into the later stages of plant growth.

Previous Experiments With Infrared Radiation

Preliminary investigations were conducted by Lucas (17) to determine whether infrared radiation would be effective in the control of loose smut in wheat. Results from these preliminary experiments indicated that it may be effective.

Further research was carried on by Kleis et al. (16) using the infrared treatment. A 250-watt industrial infrared heat lamp was used as a source of infrared radiation and was mounted above a canvas belt surface. Provisions were made so that the height of the lamp above the belt surface could be adjusted. The wheat was placed in a single layer on the belt surface inside a circle, the diameter of which varied from two to four inches depending on the size of the sample required. The height of the lamp above the table was measured from the lower surface of the lamp to the exposed surface of the wheat. The temperature attained during the treatment was measured by means of a butt-welded thermocouple made from No. 30 copper and constantan wires. Small holes were drilled longitudinally through kernels of wheat and one kernel of wheat was strung on the thermocouple wire until it was directly over the thermocouple. This kernel was then placed near the center of the single layer of wheat. Several kernels were strung on either side of this kernel to shield the thermocouple from direct radiation. The millivolt potential across this thermocouple was measured by means of a Leeds-Northrup potentiometer. Millivolt readings were then converted to degrees centigrade. At the beginning of the treatment the wheat was placed below the lamp on the canvas belt and the lamp was turned on. After a desired temperature was reached, as measured by the thermocouple, the lamp was turned off. The sample was then allowed to cool slowly to room temperature.

Preliminary germination tests were conducted with loose smut infected wheat to determine the critical temperature above which the germination was greatly reduced. The wheat was treated at various lamp heights. After this was done several samples were treated at temperatures above and below this critical temperature for field planting, to determine their effect on the loose smut fungus.

Two varieties of wheat were used for the field tests. They were American Banner and Goens. The height of the lamp above the belt was 10" for the field tests and the severity of the treatment was regulated by varying the time of exposure. The temperatures attained during the treatment of American Banner were 78°, 80°, 82°, 84°, 86°, 88°, and 90°C. For Goens they were 75°, 77°, 79°, 81°, 83°, 85°, and 87°C.

The 90-degree temperature was effective in controlling loose smut in the American Banner. However, the percentage of emergence and winter survival of the 90-degree sample was considerably lower than that of the control. There was evidence of loose smut in all other treatments. The percentage of loose smut was lower in all cases than the control, which was 7.6 percent.

The 87-degree treatment was effective in controlling loose smut in the Goens wheat. There was, however, only 1.9 percent of loose smut in the control sample.

The results of these infrared treatments appeared quite favorable but further investigations were necessary before a satisfactory treatment could be developed.

Treatment By Dielectric Heating

Dielectric heating (15) was used as a treatment for the control of loose smut in wheat because it was believed that it might have advantages over other methods of heating. Heat is generated within the material to be heated and would therefore tend to create a uniform temperature throughout. Also, the wheat could be treated in larger quantities of considerable thickness.

The source of power used was a Westinghouse industrial radio frequency generator with a rated capacity of one kilowatt. It was adjusted to oscillate at 10 megacycles, which is its design frequency for dielectric heating. The wheat was contained by a light cardboard retaining ring. The diameter of the ring was 4.78" and it was 1" high. On each side of the cardboard ring was a circular plate made of galvanized iron and 9" in diameter. Each circular plate was mounted on ½" insulation board and ½" plywood and connected to the lead terminals.

The temperature within the sample was measured by means of a copper-constantan thermocouple made of No. 30 wires. It was inserted through a small hole in the cardboard ring mid-way between the galvanized iron plates. The millivolt potential was measured with a Leeds-Northrup potentiometer and converted to degrees centigrade.

The variety of wheat used in the dielectric heating experiments was Illinois 1-128, a spring wheat. One-half pound of this wheat was used for each treatment. This was placed in the cardboard retaining ring and the thermocouple was placed approximately in the center of the sample. The power was turned on, and the current passing through the wheat was adjusted to two amperes for all tests with dielectric heating. When a predetermined temperature was attained within the sample, the power was turned off. A second temperature measurement was made sixty seconds after the power was turned off because of interference by the electrostatic field on the initial temperature measurement. The second temperature reading, called the 60-second temperature, was used because of the closer relationship between this temperature and time of exposure.

A number of germination tests were conducted to determine the critical germination temperature as previously discussed. It was found to be 90°C. This is several degrees higher than was found for the same variety of wheat treated with infrared radiation. A number of samples of loose smut infested wheat were treated at a temperature both above and below this critical temperature and planted in the field to determine the effect on the loose smut fungus. One hundred kernels from each treatment were taken from the center of each sample and hand planted in rows so that counts could be made later. The remainder of each sample was drilled in the field for comparison purposes.

Sixty-second temperature treatments of 99°, 96.2°, 95°, and 93.8°C. showed no smutted heads in the hand planted plots. This was not substantiated by the drilled plot. The emergence, in most cases, was very low where no loose smut was evident.

In view of the inconsistency between the temperature readings and field results for the same replication, it appears that this method of treatment needs further study. One definite disadvantage of dielectric heating is the high cost of the dielectric heating equipment.

TREATMENT WITH INFRARED RADIATION

Objectives

The results of previous investigations (15, 16) indicated that infrared radiation may be effective in the control of loose smut. It is believed that the margin between the temperature which affects the wheat germ and the temperature which affects the loose smut fungus is sufficiently wide to permit this treatment. Further research was necessary however, to determine the optimum exposure time and lamp height which would effectively control the loose smut fungus without causing a marked reduction in the percent of emergence.

The Nature of Infrared Energy.

Infrared energy is one form of energy in the electromagnetic spectrum. The infrared band in the spectrum is relatively wide and lies between the visible and radio bands. The wave length varies from 7600 to 1,000,000 Angstrom units (Figure 3). Generally speaking, the shorter wave lengths within this region, have the ability to penetrate, and this infrared radiation is readily converted to heat energy.

Radiation waves travel with a velocity V, which depends upon the medium through which they are propagating. The frequency of radiation, f, is dependent only on the source and does not vary with the medium. The ratio $V/f = L$ is called the wave length of the radiation. The wave length depends on the medium through which it is propagated as well as the source (4).

Factors Affecting Absorption and Reflection.

When radiant energy falls upon a body, part or all of it may be

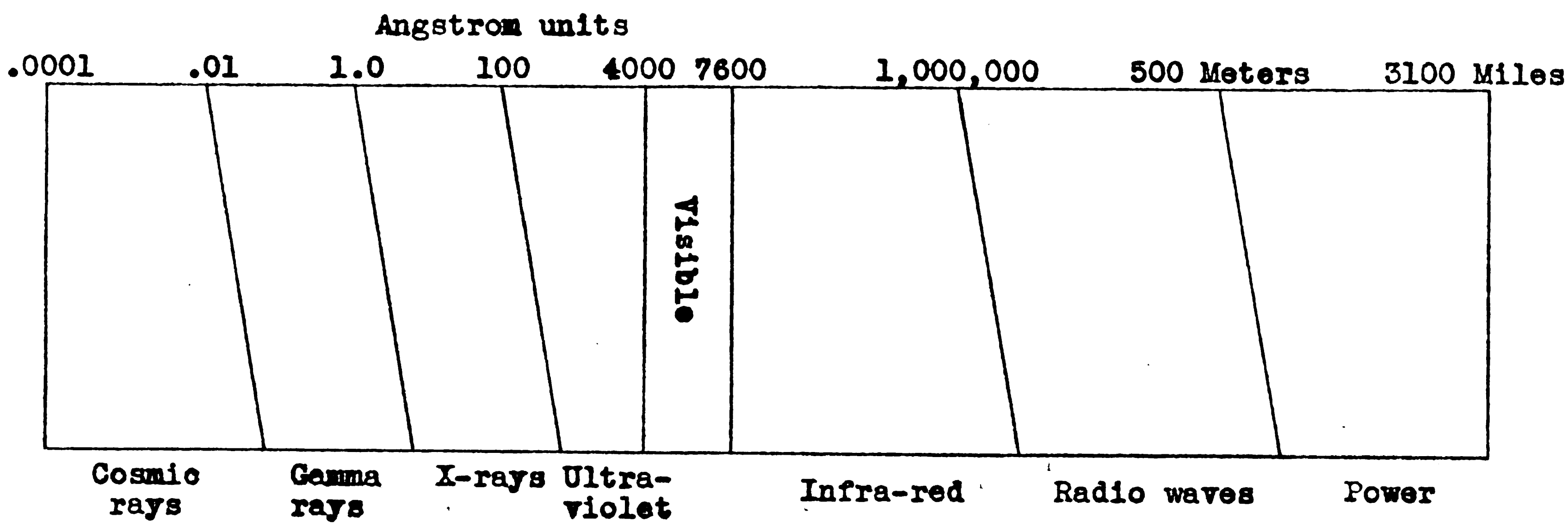

Figure 3. Electromagnetic spectrum showing the infrared region.

absorbed, part or all of it may be reflected, and part or all of it may be transmitted. Most solids are opaque to nearly all thermal radiation. Consequently, the absorption takes place within a very thin surface layer. An opaque body is a body which will absorb or reflect all of the radiant energy incident upon it. Wheat is considered to be opaque. Therefore, none of the incident radiation will be transmitted. All of it will be either absorbed or reflected. The total incident radiation will then be equal to the absorbed radiation plus the reflected radiation (4).

$$q_a + q_r = q_t \qquad (1)$$

$$\text{or if } \frac{q_a}{q_t} = a \quad \text{and} \quad \frac{q_r}{q_t} = r$$

$$\text{then } a + r = 1$$

where: a = absorptivity, or fraction of the incident radiation absorbed,

and r = reflectivity, or fraction of the incident raidation reflected at the surface.

It can be seen from equation (1) that as the absorptivity increases, the reflectivity decreases and as the reflectivity increases the absorptivity decreases. The values of a and r vary with the wave length of the incident radiation. The wave length most readily absorbed by a body is affected by the temperature of that body.

A gray body is one which has a constant absorption factor, a, for all wave lengths and temperatures. It is common practice to use the mean of the absorption factors for the temperature range involved.

A black body is a body which will absorb all of the radiant energy incident upon it. Theoretically, its absorption factor, a, is equal to one. Actually, there are no black bodies. The absorption factor, a, is defined as the ratio of the amount of radiant energy absorbed by a body to

the amount absorbed by a black body.

The amount of radiation that a body will absorb depends on a number of factors. In the case of wheat, they are: (1) temperature of the wheat, (2) color of the wheat, (3) size and uniformity of kernels, (4) surface finish, (5) moisture content, (6) chemical composition, (7) amount of surface area exposed to the radiant energy. The size and uniformity of these kernels would probably be most easily controlled, within limits. This could be done by screening the wheat before treatment to avoid wide variations within the same sample. Kernels of different sizes which are given the same treatment would probably respond differently because of different rates of heating. The other factors would be relatively constant for any one sample of wheat.

Apparatus and Equipment

The source of infrared energy was an R-40, 250 watt, reflector-type, infrared heat lamp. This lamp was used as a source because of its simplicity, availability and low cost. The operating temperature of the tungsten filament inside this lamp is about 4,000°F. The wave length of the greatest amount of energy is 12,000 Angstrom units (Figure 4). The size of the samples treated was necessarily small because of the rapid decrease in radiation intensity as the distance from the central axis increases (Figure 5).

This lamp was mounted on an adjustable stand above a flat plywood surface as shown in Figure 6. The size of each sample treated throughout this investigation was approximately one hundred seeds. These were placed in a single layer on heavy folder paper directly below the central axis of the lamp. They were placed within a 2" circle on the folder paper;

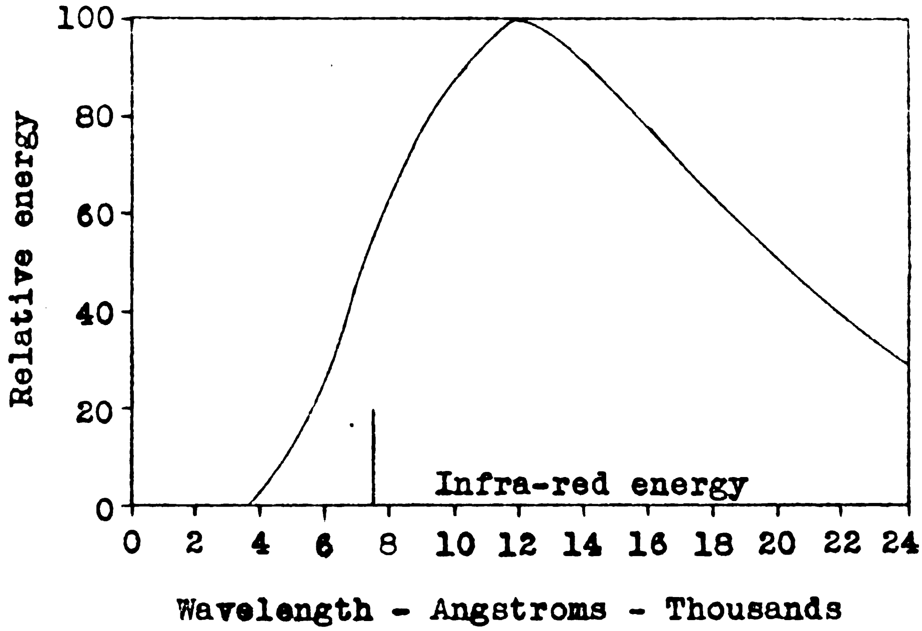

Figure 4. Wavelength distribution of a 250-watt infrared heat lamp.

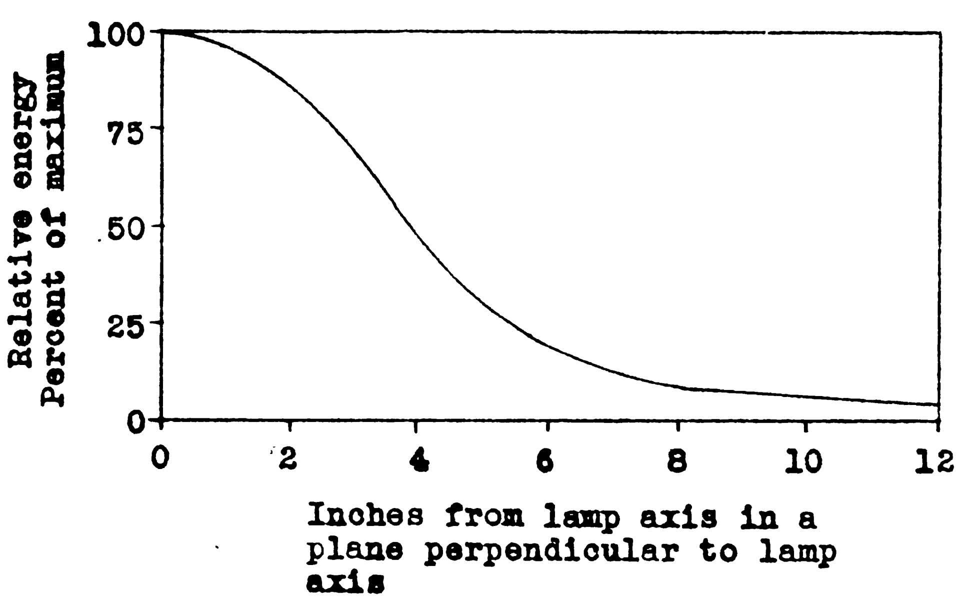

Figure 5. Energy distribution of a 250-watt infrared heat lamp.

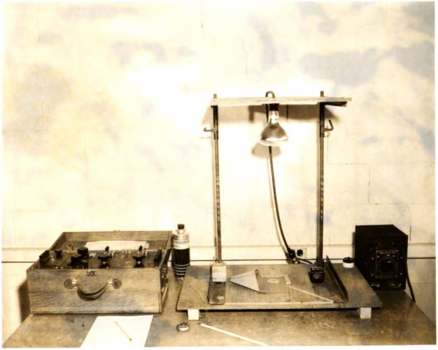

Figure 6. Infrared heating apparatus.

guides were constructed on the plywood surface to insure the same placement of each sample under the lamp. One end of the folder paper was shaped in the form of a funnel to facilitate rapid transfer of the wheat into a temperature measuring device immediately after the treatment.

The temperature measuring device consisted of a cylinder of finely granulated cork, 2 inches in diameter and 2 inches long, set in a small wooden block. See Figure 7. Cork was used because of its low absorptivity. A 3/4" hole, 1½" deep was drilled into the center of the cork cylinder. After a sample was transferred to the temperature measuring device, a cork stopper was placed in the hole to prevent a rapid loss of heat from the wheat to the outside air.

The temperature was measured by means of a butt-welded thermocouple made from No. 24 copper and constantan wires. This thermocouple was centered in the lower portion of the cylindrical cavity as indicated in Figure 7. A light sheet metal strap was fastened to the cork stopper by means of a small screw. This fit comfortably over the left forefinger and facilitated rapid placement of the stopper in the hole after the wheat was introduced. The highest millivolt potential across the thermocouple was immediately measured with a Leeds-Northrup potentiometer. This was then converted into degrees centigrade, by means of prepared tables. Temperatures were read to the nearest one-half degree centigrade. The time required to transfer the wheat into the temperature measuring device was about 2 seconds. The time required to obtain the highest reading was about 20 seconds after the transfer began, and was a function of the reaction time of the potentiometer and not the speed of the operator. Figure 8 shows the rate of heat loss from this temperature measuring device after the highest temperature reading was obtained.

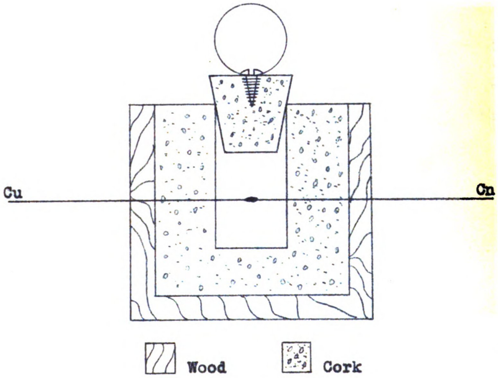

Figure 7. Temperature measuring device used in infrared tests.

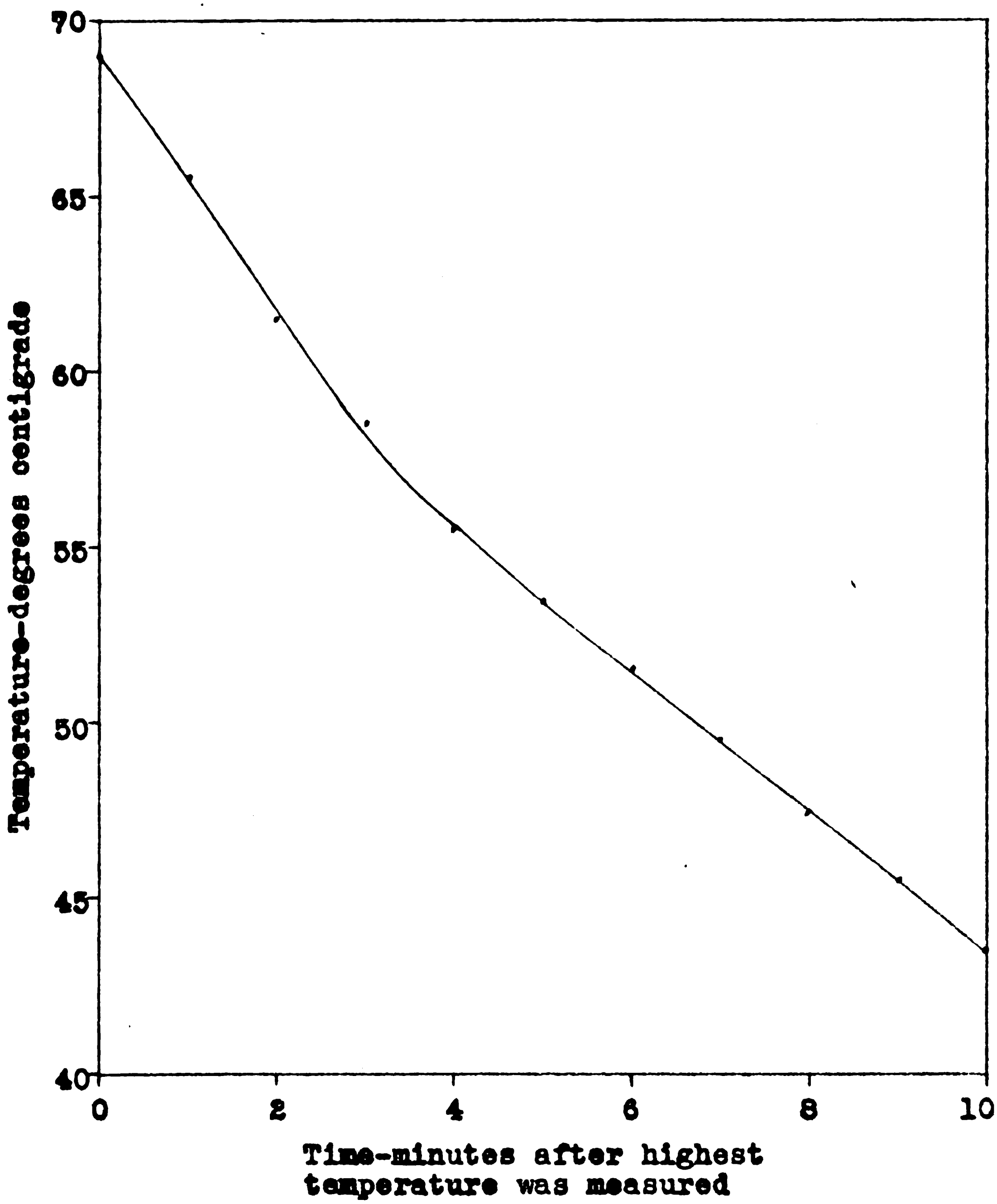

Figure 8. Rate of heat loss from temperature measuring device.

This temperature measuring device measures the temperature of the micro-atmosphere about the wheat kernels. The temperature readings obtained are relative. Hereafter, when reference is made to temperature readings with the infrared radiation treatments, readings as obtained by this method of measurement are implied.

The surface of the wheat which was exposed to the infrared radiation will reach a higher temperature than the surface in contact with the folder paper. This could result in widely different temperature readings for the same treatment. However, it is believed that the surface temperature of the whole kernel and of the dead air spaces between the kernels will reach an equilibrium temperature very shortly after being transferred to the temperature measuring device. A voltage adjuster was connected in the circuit so the voltage to the lamp could be adjusted to 120 volt for all tests.

Experimental Procedure

The variety of wheat used throughout this research was the 1951 crop of Illinois 1-128, a fast growing spring wheat having a high susceptibility to loose smut. Its moisture content was measured by a Steinlite capacitance—type meter. This was found to be approximately nine percent for the wheat used in all the infrared tests. Each day before treatment began, several samples of wheat were heated to temperatures approaching those expected from the treatments and placed in the temperature measuring device. This was done to preheat the cup, thereby lowering the temperature gradient between the wheat and cork which resulted in more reliable temperature readings. Except for a number of preliminary tests, all treatments were made in a controlled temperature room which was maintained at 77.5°F.

This eliminated the initial temperature of the wheat as a factor affecting the treatment.

A wheat sample consisting of approximately 100 seeds was placed in a single layer inside the two-inch circle on the folder paper. The lamp was then turned on for a period of 3 minutes for most tests. The three-minute time exposure was chosen arbitrarily and the height of the lamp above the surface was varied. The height of the lamp above the table was measured from the lower end of the bulb to the surface of the folder paper. After the three-minute treatment the wheat sample was immediately transferred to the temperature measuring device and the highest temperature reading recorded. The sample was then placed in a small envelope and allowed to cool slowly to room temperature. Each sample was tested for germination by placing fifty seeds on moist filter paper in each of two Petri dishes. Some samples were planted in greenhouse flats for emergence and loose smut control tests.

Effect of Surface Heating.

After a number of preliminary tests it was found that a change in the temperature of the plywood surface around the sample affected the final temperature reading. This was due to the natural convection currents originating directly above the heated wheat. When this heated air above the sample rises, cooler air is drawn in from the surrounding surface and cools the wheat. This interfering factor was minimized by turning the lamp on for one hour before testing began to insure an equilibrium temperature of the surrounding surface.

Determining Critical Treatment.

Ninety-six tests were conducted in an effort to determine a certain critical treatment, where a more severe treatment would cause a marked drop in the germination percent. The height of the lamp was varied from 4 to 18 inches. Each sample was treated for three minutes. After the approximate critical height range was determined, the length of treatment was varied from two to four minutes. A critical treatment was found to be ten inches for three minutes. Samples were subjected to a more severe and a less severe treatment by varying the lamp height below and above ten inches, respectively, to determine the effect on germination before planting in the field.

Effect of Sudden Cooling.

It had been suggested that perhaps a sudden cooling of the heated wheat may have an adverse effect on the loose smut fungus, and a favorable effect on the embryo of the wheat. A number of tests were conducted to determine the effect of both a rapid chill and a slow chill on the heated wheat. The wheat was cooled by placing a small envelope containing the wheat between two pieces of dry ice. A thermometer was placed in the sample to measure its temperature.

In both the rapid and slow chill the wheat was cooled to $0^{o}C$. The slow chill required twenty minutes, the rapid chill required one and one-half minutes. These time periods are arbitrary and were determined experimentally by varying the distance between the sample and the dry ice. Each treatment was duplicated. The mean germination percentages of samples subjected to a severe treatment (9" - 3 minutes) and chilled are shown in Table 2. The germination result of the slowly cooled sample shows an increase of approximately 50% over the non-chilled and rapidly chilled samples. Because of this encouraging result, it was decided to include a slowly chilled sample in the field tests.

Table 2. Effect of sudden cooling after treatment, on germination.

Lamp height (inches)	Time (minutes)	Temperature °C.	Cooling rate	Germination %
9	3	78	Slowly cooled to room temp.	56
9	3	78.5	Cooled to 0°C. in 20 min.	81
9	3	78.5	Cooled to 0°C. in 1.5 min.	51
Control	-	-	-	94

Field Tests

After preliminary germination tests were completed, and a critical treatment was established, it was decided to conduct field tests on a number of different treatments to determine the degree of smut control. Six different treatments were used for field tests. They are shown together with germination results in Table 3.

Treatment 4 was included in the field tests because it was suggested that perhaps a greater lamp height for a longer exposure time may have the effect of dehydrating the loose smut hyphae.

A 6 x 6 Latin Square design was used for the field tests. There were 100 seeds in each plot, making a total of 600 seeds for each treatment. The 100 seeds were planted in one 16-foot row with an approximate spacing of two inches between seeds. The rows were 6 inches apart. Six guard rows were planted on both sides of the square, parallel to the test rows to protect against fringing effects.

Table 3. Effect of varying lamp heights on germination.

Treatment Number	Lamp Height (inches)	Time (minutes)	Temperature °C.	Percent Germination
1	11	3	66.5	90
2	10	3	72.0	88
3	9	3	77.0	56
4	16	20	57.5	93
5*	9	3	76.5	81
6 (Control)	-	-	-	94

* Slowly chilled following treatment.

Approximately two weeks after planting, emergence counts were made. About one month later, during the blooming period, counts were made of the smutted plants. The emergence and smut results are shown in Table 4. A summary of these results appears in Table 5.

Statistical Analysis of Field Results.

The frequency distribution of each treatment according to its emergence count and number of smutted plants is given in Table 6. The figures in the body of the table are the treatment numbers (Table 4) with no designation being made as to replication. It is seen that treatments 3 and 5 belong to a population different in emergence counts, from the other four treatments. Likewise, treatment 2 tends to belong to a second population as to emergence counts. Treatments 1, 4, and 6 belong to still a third population. The percentages of emergence of treatments 3 and 5 are so low that they were not included in the analyses of variance. The analyses of variance and covariance on treatments 1, 4, and 6 indicate there were no significant differences between these three treatments in the percent of emergence and in the percent of smutted plants. (Tables 7, 8, and 9). Also, there is no relationship between the percent of emergence and the percent of smutted plants.

Discussion of Field Results.

The percent of emergence of all treatments was quite low. Because the emergence of the control was also reduced, this lack of emergence cannot be attributed entirely to the infrared treatment. A number of other factors may have been the cause of low emergence. The shoots may have had difficulty in breaking through the soil which was hard, lumpy, and dry at the time of planting. Wheat from the same lot which was used for

Table 4. Field test results from infrared treatments.

Trt. No.	Replication	Lamp Height (inches)	Time (minutes)	Temp. °C.	% Emergence	% Smutted Plants
Control	1	-	-	-	59	4
Control	2	-	-	-	68	5
Control	3	-	-	-	75	4
Control	4	-	-	-	64	2
Control	5	-	-	-	64	3
Control	6	-	-	-	63	6
1	1	11	3	66.5	66	6
1	2	11	3	65.5	55	3
1	3	11	3	66.5	68	6
1	4	11	3	66.5	71	4
1	5	11	3	66.5	59	6
1	6	11	3	65.5	48	4
2	1	10	3	72.0	55	0
2	2	10	3	71.5	29	0
2	3	10	3	71.5	35	1
2	4	10	3	72.0	30	0
2	5	10	3	72.5	31	1
2	6	10	3	72.5	21	0

Table 4. (Continued)

Trt. No.	Replica-tion	Lamp Height (inches)	Time (minutes)	Temp. °C.	% Emergence	% Smutted Plants
3	1	9	3	76.5	19	0
3	2	9	3	77.5	1	0
3	3	9	3	77.5	6	0
3	4	9	3	77.5	4	0
3	5	9	3	78.5	3	0
3	6	9	3	78.5	2	0
4	1	16	20	57.5	63	3
4	2	16	20	57.5	58	5
4	3	16	20	57.5	49	2
4	4	16	20	58.0	70	5
4	5	16	20	57.5	54	3
4	6	16	20	57.0	60	3
5*	1	9	3	76.0	3	0
5*	2	9	3	75.5	6	0
5*	3	9	3	75.5	4	0
5*	4	9	3	76.5	1	0
5*	5	9	3	76.5	1	0
5*	6	9	3	76.5	10	0

*Slowly chilled following treatment.

Table 5. Summary of field tests.

Lamp Height (inches)	Time (minutes)	Temperature °C.	Percent Emergence	Percent Smutted Plants
11	3	66.5	61	4.8
10	3	72.0	34	.3
9	3	77.0	6	0
16	20	57.5	59	3.5
9*	3	76.0	6	0
Control	-	-	66	4.0

* Slowly chilled following treatment.

Table 6. Frequency distribution by treatment number, of field results.

Percent Emergence	Percent Smutted Plants: 0	1	2	3	4	5	6
0–4	5,3,5,3, 5,3,5,3						
5–9	5,3						
10–14	5						
15–19	3						
20–24	2						
25–29	2						
30–34	2	2					
35–39		2					
40–44							
45–49			4		1		
50–54				4			
55–59	2			6,1		4	1
60–64			6	4,6,4			6
65–69						6	1,1
70–74					1	4	
75–79					6		

Table 7. Analysis of variance of field emergence results.

Source	df	SS	MS	F
Total	17	928	-	-
Replication	5	244	-	-
Treatment	2	131	65.5	1.18
Error	10	553	55.3	-

$F_{2,10}$ at 5% is 4.10

Table 8. Analysis of variance of field smut results.

Source	df	SS	MS	F
Total	17	32	-	-
Replication	5	1	-	-
Treatment	2	6	3	1.2
Error	10	25	2.5	-

$F_{2,10}$ at 5% is 4.10

Table 9. Analysis of covariance of field results.

Source	df	Emergence A Sx^2	B Sxy	Smut C Sy^2	$b=\frac{B}{A}$	bB	C-bB	df adj.	MS
Replication	5	244	-12	1	-	-	-	-	-
$Treatment_1$	2	131	5	6	.038	.19	5.81	1	-
$Error_2$	10	553	69	25	.125	8.61	16.39	9	$V_2=1.82$

$$F = \frac{b_2B_2}{V_2} = \frac{8.61}{1.82} = 4.73$$ - not significant

$F_{1,9}$ at 5% is 5.12

field planting was later found to be infected with a fungus, Rhizopus. This fungus growth may have been aggravated under adverse conditions such as low night temperatures. The field planting was done under the supervision of the Farm Crops Department.

The marked reduction in percent of emergence of treatments 2, 3 and 5, was, undoubtedly, the result of the severe treatments which probably killed or damaged the wheat germs, thereby affecting the emergence.

Treatments 3 and 5 were completely effective in controlling the loose smut fungus. However, the emergence of these two treatments was so extremely low that this is of little significance. Treatment 5 which was slowly chilled to 0°C. immediately after treatment resulted in an increase of about 50 percent in germination over the same treatment followed by slow cooling to room temperature. However, there was practically no difference in the percent of emergence of these two treatments. This would tend to indicate that the wheat germ is damaged by the heat treatment to the extent that the shoot cannot push through the soil. The most favorable conditions for germination are usually maintained in Petri dishes. Therefore, a slight resuscitation of the wheat may be noticeable in a germination test but not in an emergence test.

There was evidence of loose smut in all other treatments. However, there were only two smutted plants of six hundred in treatment 2. The emergence of this treatment was considerably lower than that of the control. A somewhat lower emergence could be tolerated if there was complete control of loose smut. The planting rate would need to be adjusted to compensate for this loss of emergence.

Factors Affecting Reproduceability of Infrared Treatments

Considerable difficulty had been experienced in duplicating temperature readings for the same treatment. Before proceeding with any further field tests it was decided to investigate the reasons for these variations and determine the practicability of using infrared radiation as a treatment.

It had been hoped that there would be a safe temperature margin between the killing temperature of the wheat germ and the killing temperature of the loose smut fungus. However, the results from the field tests indicate that this margin is very narrow. Throughout all the foregoing treatments with infrared radiation, the temperature readings obtained from samples subjected to the same treatment varied as much as $\pm$ 1°C. or more in some instances. This can be seen in Table 4. Variations of $\pm$ 1°C. were the smallest that could be obtained. This variation could very well mean the difference between killing the smut fungus and killing the wheat germ. In most instances, a higher temperature resulted in a lower germination and a lower temperature resulted in a higher germination. Following is a discussion of a number of factors affecting the reproduceability of the infrared treatments.

Air Currents.

The effect of convection currents originating directly above the wheat sample on the temperature attained, as previously discussed, was minimized by turning the lamp on for a period of one hour prior to treatment. Air currents originated unintentionally by the motion of the operator during treatment or just before transferring the wheat to the temperature measuring device also affected the temperature attained. Other air currents produced by natural drafts, heaters or ventilators in the room also contributed to this error.

Relative Humidity.

Efforts to duplicate treatment 2 of the field tests actually led to an investigation of the factors affecting the reproduceability of infrared treatment. Samples of treatment 2 were treated for the field tests on May 6, 1952, in a controlled temperature room. The temperature attained for each of six replications was 72 ± 0.5°C. (Table 4). On July 29, 1952, an attempt was made to duplicate treatment 2. The same variety of wheat was used, at the same temperature in the same room. The apparatus, equipment, and operator were the same as before. All the conditions were exactly the same except the wheat was being treated on a different day. The highest temperature obtained after two hours of treating was 66.5°C. The relative humidity on May 6 was 25.3 percent. On July 29 the relative humidity was 61 percent. Absorption of the infrared radiation by the water vapor in the air was immediately suspected. It was decided to conduct further tests to determine if relative humidity was actually a factor affecting reproduceability of the infrared treatments.

Since it was recognized that relative humidity was an interfering factor, temperature measurements at other relative humidities were taken. Because of lack of time, however, only two essentially different humidity levels were investigated.

The relative humidity in the controlled temperature room was determined on different days with a sling psychrometer. Tests were conducted on four different days using a lamp height of ten inches and varying the time exposure between three and five minutes. Results of these tests are shown in Table 10. The results show relative humidities of 61, 62, and 63 percent to be in close agreement. A relative humidity of 40 percent resulted in a higher temperature attained after three minutes. Also, an

Table 10. Effect of different percentages of relative humidity on the temperatures attained for a 10-inch lamp height, and 3-5 minute treatment.

Time (Minutes)	July 29 1952 R.H. 61%	August 4 1952 R.H. 62%	August 5 1952 R.H. 63%	July 31 1952 R.H. 40%
	Temperature °C.			
3	66.5	66.5	66	71
3.5	68.5	69	68.5	73
4	69	70	69	73
4.5	71	72	70	73
5	72	72	72	73

equilibrium temperature was attained after about three and one-half minutes. This would indicate that when the relative humidity is lower, there is less atmospheric absorption which results in a higher temperature attained in a shorter period of time. This is a seriously interfering factor and one which will vary from day to day and even from one hour to the next. Furthermore, it is a factor which cannot easily be controlled.

Embryo Position.

Results of previous germination tests sometimes indicated widely varying germination percentages for samples subjected to the same treatment and having attained the same temperature. A factor contributing to this variation was embryo position. If the wheat was placed under the lamp with the embryo up, the embryo was subjected to direct radiation from the lamp. Conversely, if the wheat was placed under the lamp with the embryo down, it would be exposed to practically no direct radiation and its chances of survival would be much better.

Several tests were conducted to determine the effect of embryo position on the germination. Samples with all embryos up and all embryos down were subjected to a very severe treatment. The samples with embryos down had a germination of fifty percent greater than those samples with embryos up. This difficulty might be overcome by keeping the wheat in constant motion during treatment to insure that one side is subjected to approximately the same amount of radiation as the other. This could be done by using a vibrator.

At this point in the research, two months were spent on improving the infrared apparatus and equipment. These improvements were made in an attempt to eliminate some of the error contributing to the inconsistent results. Among the improvements made was the use of a belt surface as a base instead of the folder paper. A 4" x 5" belt at room temperature was used for each treatment, thereby eliminating the heated base as a factor. Also, three thermocouples were inserted in the temperature measuring device to give a more representative temperature reading. Provisions were also made for a more efficient transfer of heated wheat to the temperature measuring device. In spite of all these improvements, inconsistent germination and temperature results were still in evidence.

In view of the inconsistent results obtained from the infrared treatments and the nature of the interfering factors, it was decided to abandon the use of this method of treatment. The interfering factors cannot be easily controlled. Perhaps a different source of infrared energy would be more desirable. A lower temperature and more uniform source which is in direct contact with the wheat from two sides would eliminate relative humidity, embryo position and air currents as interfering factors.

TREATMENT WITH OVEN HEAT

Objectives

Because infrared treatments could not be accurately reproduced, there was a need for a source of heat energy which could be closely controlled. A review of literature revealed the investigations of Caldecott and Smith (5), and Suskind (27) on the resuscitation of heat-inactivated seeds by x-radiation. In the experiments conducted by Caldecott and Smith, wheat was subjected to a lethal heat treatment in an electric oven. The wheat was then exposed to x-radiation to determine the effect of post-irradiation on the heat-inactivated seed. Suskind later made an attempt to duplicate the results obtained by Caldecott and Smith. In attempting to work with an electric oven, he found the temperatures to vary as much as $\pm$ 15°C. from the desired point of treatment. To overcome the difficulties encountered, Suskind used an Abderhalden heating apparatus for the heat treatment of wheat. Tests were conducted to determine the lethal temperature of wheat. The same variety of wheat was used in both investigations. Suskind could not duplicate the observations of Caldecott and Smith.

Results of these previous investigations indicated that wheat would survive after being subjected to oven treatments using unexpectedly high temperatures. Because of this interesting fact, it was decided to study the use of an electric oven as a source of heat for the control of loose smut in wheat.

Fungus hyphae are very much dependent on moisture for their survival. There is a definite possibility that extensive dehydration of the loose smut fungus would harm the microorganism more than the seed of the host plant. To obtain a sufficient drying effect the length of treatment would need to be increased considerably over that used for the infrared tests.

The immediate objectives of these oven treatments were to determine: (1) what temperatures and periods of treatment wheat seed would tolerate without appreciable loss of viability and (2) whether there was a trend in the control of loose smut with increasing temperature and length of treatments.

Apparatus and Equipment

It was necessary to use an electric oven which would give very close temperature control so that treatments could be accurately reproduced. After experimenting with several available electric ovens, the Cenco Electric Vacuum Oven was found to be the best answer. This oven is cylindrical in shape and is surrounded by an oil bath (Figure 9). The oil is heated by four 250-watt knife-type electrical immersion heaters. Two of these can be controlled by a thermoregulator. The other two are controlled manually. Since the oven is heated by the oil, the temperature can be controlled within very close limits. The oven is equipped with an inner door and an outer door for sealing the open end. This provides a uniform temperature inside the oven. It can easily be controlled to within $\pm$ 0.5°C.

The oven used is about twenty-five years old, and of a type which is no longer being manufactured. It is, however, in excellent condition and has operated satisfactorily throughout this investigation. It is equipped with a vacuum pump for reducing the pressure inside the oven. This was not used in the oven experiments. All tests were conducted at the existing atmospheric pressure. Two centigrade thermometers were used to measure the temperature inside the oven and of the oil bath.

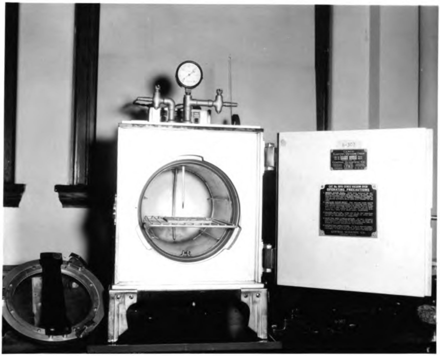

Figure 9. Cenco Electric Vacuum Oven.

Experimental Procedure

The same variety of loose smut infected wheat (Illinois 1-128) was used for the oven treatments as was used in the infrared tests. Its moisture content was measured by the Steinlite capacitance type meter and found to be 8 and 3/4 percent. This was later verified by oven drying a sample of the same wheat.

Approximately one hundred seeds were used for each treatment. These were placed on a 4" x 5" piece of cotton belt. Belt was used as a base because it would lend itself to a continuous system for large scale treatment of wheat. After the oven was heated to the desired temperature, the doors were opened and the belt was placed on a shelf inside the oven as shown in Figure 9. Timing of each treatment began after the oven had again reached the desired temperature. In most instances, this required about fifteen minutes after introducing the wheat. The heaters were manually controlled as it was possible to obtain much closer temperature control than by using the thermoregulator.

Preliminary germination tests were conducted to determine the approximate lethal temperatures of wheat. Twenty-one samples were treated for one-half, one and two hours at temperatures of 60°, 65°, 70°, 75°, 80°, 85°, and 90°C. Treated samples were allowed to cool slowly to room temperature. One hundred seeds from each sample were then placed on moist filter paper in two Petri dishes for germination tests as previously discussed. None of these treatments were found to have a killing effect on the wheat germ.

It was then decided to treat samples for one hour at temperatures of 92°C. and above at two degree intervals until a lethal temperature was reached. Samples were treated for one hour at 104°C. before there was a marked reduction in the germination percentage (Figure 10). The germination of all samples treated for one hour at temperatures of 90°C. and above was somewhat delayed.

A very critical factor involved in plant survival is root development. For this reason, the weight of radicles from each sample treated at a temperature above 90°C. was measured. This was used as a criterion in determining the highest oven temperature to be used for smut control tests. All samples whose weight of roots was measured were planted in sterilized quartz sand in Petri dishes. This was done to facilitate removal of the plants without damage to the roots. After a 72-hour germination period, the roots from each sample were clipped and weighed. Table 11 shows the weight of radicles together with germination results of several samples treated at various temperatures for one hour.

Greenhouse Tests

After lethal germination temperatures were determined, treated wheat was planted in the greenhouse for a preliminary smut control test. Table 11 shows a relatively sharp drop in the weight of radicles from samples heated at 104°C. for one hour. This is accompanied by a rather marked drop in germination percentage. Consequently, the highest temperature used for greenhouse tests was 102°C.

It was decided to use treatments of 98°, 100° and 102°C. for one-half, one and two hours for the smut tests. One control sample plus the nine heat treated samples made a total of ten different treatments. Three replications were made of each treatment. These were planted in a randomized block design so the results could be statistically analyzed. The

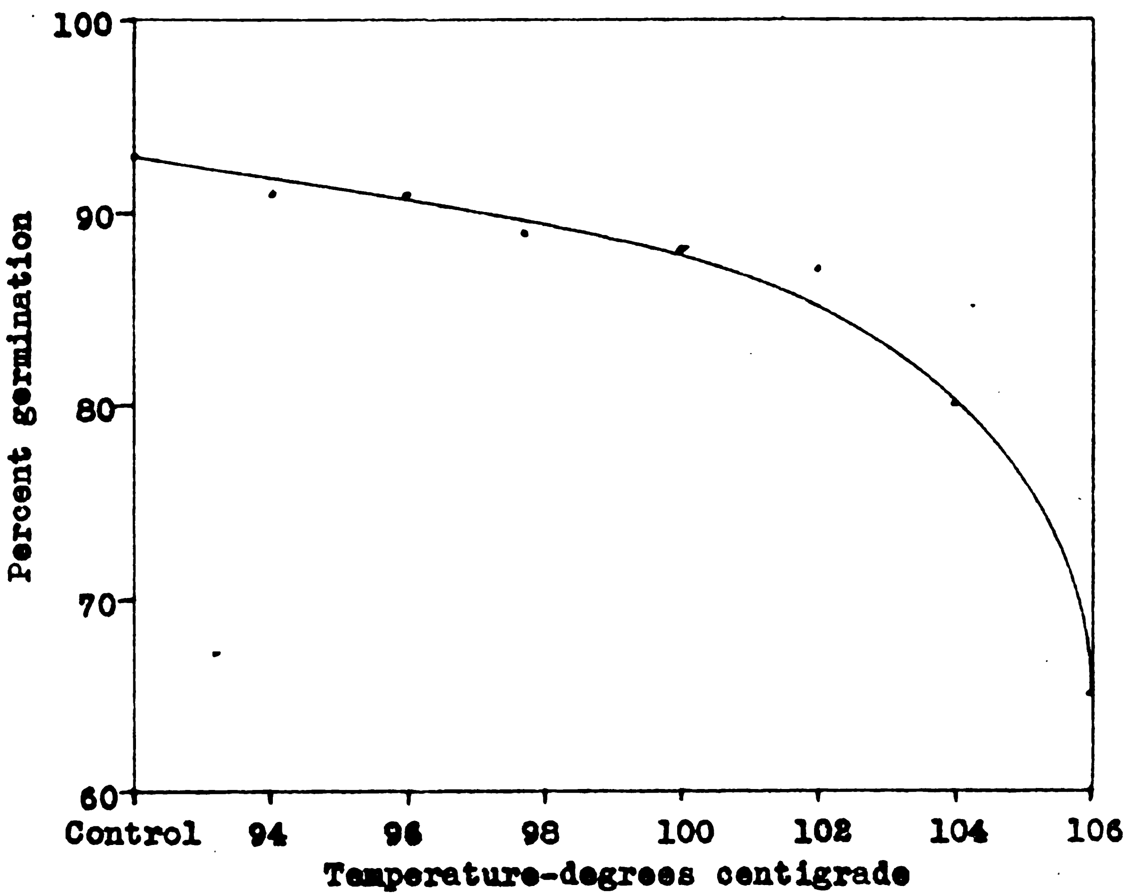

Figure 10. Effect of temperature on germination of Illinois 1-128 wheat for a one-hour treatment.

Table 11. Effect of a one-hour treatment at varying temperatures on germination and weight of radicles after a 72-hour germination period.

Temperature °C.	Percent Germination	Weight of Radicles from 100 seeds-gm.
96	91	2.46
98	89	1.96
100	88	1.76
102	87	1.62
104	80	1.26
106	65	1.00

treatment numbers and treatments which were used for greenhouse tests are shown in Table 12.

Table 12. Treatments for greenhouse tests.

Treatment number		Temperature °C.	Time minutes
1		102	30
2		102	60
3		102	120
4		100	30
5		100	60
6		100	120
7		98	30
8		98	60
9		98	120
10	Control	-	-

The samples were planted in a greenhouse bench as shown in Figure 11. There were 125 seeds in each treatment. These were planted in two rows across the width of the bench. Row spacing was 4" and seed spacing was approximately 3/4". Two guard rows were planted parallel to the test rows to eliminate fringing effects.

Four 300-watt lamps with reflectors operated by an electric timer, were mounted above the greenhouse bench as shown in Figure 11 to extend the period of light to approximately 12 hours.

Two weeks after planting, emergence counts were taken. Approximately two months after planting, smut counts were made. These results appear in Table 13. The figures in the body of the table are the number of emerged and smutted plants from 125 seeds.

Figure 11. Oven treated wheat growing in a greenhouse bench.

Table 13. Emergence and smut results from greenhouse tests.

		Replication					
		1		2		3	
		No. of Plants		No. of Plants		No. of Plants	
Tempera-ture °C.	Time (Min.)	Emerged	Smutted	Emerged	Smutted	Emerged	Smutted
Control		123	5	118	6	116	0
98	30	108	2	109	2	111	0
98	60	98	2	110	1	110	1
98	120	103	1	102	1	103	0
100	30	117	3	113	0	106	0
100	60	106	0	99	0	103	0
100	120	103	0	87	0	99	0
102	30	116	2	107	0	84	0
102	60	90	0	84	0	86	1
102	120	91	0	92	0	97	0

Statistical Analysis of Greenhouse Results.

The frequency distribution of each treatment according to its emergence count and number of smutted plants appears in Table 14. The figures in the body of the table are treatment numbers without regard to replication. An analysis of variance of the emergence results is shown in Table 15. This indicates that time and temperature were both highly significant factors in the oven treatments.

Discussion of Greenhouse Results.

A summary of the oven greenhouse results is given in Tables 16 and 17. The numbers which appear in the body of these tables are the number of emerged or smutted plants from 125 seeds.

There appears to be a marked drop in the number of smutted plants at a temperature between 98° and 100°C. and at a treatment length of between thirty and sixty minutes (Table 17). A similar break appears in the number of emerged plants, although this is not so pronounced (Table 16). This tends to indicate that a temperature of 98°C. is not high enough to control loose smut. Also, there are indications that a thirty-minute oven treatment is too short to control loose smut. There seems to be a trend toward a decreasing number of smutted plants with an increase in temperature above 98°C. and an increase in the period of treatment longer than thirty minutes.

Table 14. Frequency distribution by treatment number, of the results from greenhouse tests.

Number of Plants Emerged	Number of Smutted Plants						
	0	1	2	3	4	5	6
0 5							
6 11							
12 17							
18 23							
24 29							
30 35							
36 41							
42 47							
48 54							
55 60							
61 66							
67 72							
73 78							
79 84	1,2						
85 90	2,6	2					
91 96	3,3						
97 102	3,5,6	9	8				
103 108	1,4,5,5 6,9	9	7				
109 114	4,7	8,8	7				
115 120	10		1	4			10
121 126						10	

Table 15. Analysis of variance of emergence results from greenhouse tests.

Source	df Total	df Active	S.S.	M.S.	F
Total	29	29	3311	-	-
Replication	2	2	93	46.5	-
Treatment	9	-	2374	263.8	5.65**
Control: Others	1	1	849	-	-
Within Others	8	-	1525	191	4.1**
Time	2	2	715	357	7.6**
Temperature	2	2	598	299	6.4**
Time X Temp.	4	4	212	53	1.1
Error	18	18	844	46.7	-

$F_{9,18}$ at 1% is 3.60

$F_{8,18}$ at 1% is 3.71

$F_{2,18}$ at 1% is 6.01

$F_{4,18}$ at 5% is 2.93

Table 16. Summary of emergence results from greenhouse tests.

Time (Minutes)	Temperature °C. 98	100	102	Sum	
30	108	117	116		
	109	113	107		
	111	106	84		
	328	336	307	971	
60	98	106	90		
	110	99	84		
	110	103	86		
	318	308	260	886	
120	103	103	91		
	102	87	92		
	103	99	97		
	308	289	280	877	
Sum	954	933	847	2734	2734
Control					123
					118
					116
					357
Total					3091

Table 17. Summary of smut results from greenhouse tests.

Time (Minutes)	Temperature °C. 98	100	102	Sum	
30	4	3	2	9	
60	4	0	1	5	
120	2	0	0	2	
Sum	10	3	3	16	16
Control					11
Total					27

SUMMARY

The various hot water treatments are the only generally recommended methods of treatment for the control of loose smut in wheat. The disadvantages of using these treatments are: (1) the seed is wetted during treatment, (2) close temperature control is required, and (3) they are difficult and tedious to apply.

A dry heat treatment for the control of loose smut in wheat would be very desirable. This investigation was directed toward the development of such a treatment.. Dry heat treatments which were employed in this study were infrared radiation and heat generated in an electric oven. Results from the infrared tests indicate that this method of treatment might be effective if it could be controlled more closely. Several factors were found to be impairing the accuracy of the infrared treatments. They are, a difference in the degree of embryo exposure in the various samples, atmospheric absorption of some of the infrared radiation, and the effect of air currents during treatment. Since these interfering factors are of such a nature that they could not easily be controlled, it was decided to abandon the use of infrared lamps as a source of heat.

Infected seed was treated in an electric oven and planted in a greenhouse to determine the degree of loose smut control. Results from the greenhouse tests indicate a trend toward decreasing incidence of loose smut after treatment at temperatures above 98°C. and treatment periods of more than thirty minutes.

Tests on a larger scale will be necessary to determine the optimal conditions under which such a treatment is practicable. Such a treatment, if standardized, will lend itself to a continuous process for large scale treatment of wheat.

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