EXPERIMENTS ON THE PRACTICAL CONTROL OF STORED GRAIN INSECTS WITH A REVOLVING DRUM-TYPE HEATER

by

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INTRODUCTION

The control of stored grain insects is one of the major problems that farmers and grain dealers must face all over the world. In Haiti it is of considerably greater importance than in the United States. Treating the grain with fumigants has certain disadvantages. The relatively high cost of insecticides is a good argument against their common use by many grain dealers and particularly under tropical conditions, in which the writer is more especially interested their use is quite a financial burden. The Haitian farmers in general cannot afford to buy these fumigants, because of the low prices he gets for his products on the local markets. The returns obtained from a well preserved load of grain would not be high enough to compensate him for the cost of the fumigant.

CS_2 (carbon disulphide), the most effective and most used fumigant on the farms with which to treat bulk grain, is quite volatile and there are certainly many chances to lose part of it in ordinary containers or all of it if the container leaks. This is especially true in the tropics where the danger of evaporation is greater. This material besides costs in Haiti twice as much as it does in the United States, because of duty and shipping charges. There would be also the need for a tight fumigatorium for large amounts of grain, and this would mean more expense in using this fumigant.

In addition, the gas is quite inflammable and explosive and the danger of starting fire is always present whenever carbon disulphide is used somewhere. Its use in elevators voids many of the insurance policies.

On the contrary the heat treatment of stored grain insects has given very good results with relatively little expense. Such treatment has some particular advantages that would make its development quite successful in Haiti, as it is now in the United States. The heat method is recognized as one of the most effective, practical, convenient, and inexpensive of all treatments used in flour mills. There is practically no danger of injury to the equipment if the proper temperatures are applied. The chances of fire are also entirely eliminated. Besides, it was found that the cost of the appliances necessary for the heat treatment is not at all prohibitive and, compared with other methods of treatment, is covered by saving time and extra expense in less than five years.

The heat system would be by far the cheapest control for stored grains in Haiti. There the cost of labor as well as the cost of wood fuel is relatively low. Under such conditions the farmers would adopt readily such a treatment in which they could use local materials, regardless of putting in a little more time than by other methods would be able to cover the cost of treatment by the returns.

Not only the heat system has been used successfully in mills and elevators for controlling insects, but also for smaller quantities and many kinds of grain. They have devised many types of power operated revolving drums through which the infested grain is allowed to pass at a certain temperature to kill the insects in it.

Such a type of apparatus appears to be the type to be used by Haitian and small American farmers who have to treat grain on a smaller scale than is the case for large commercial dealers. But as most of these machines are rather expensive and require steam and power connections, there would not be much opportunity of having those machines adopted by small farmers.

Something cheaper and making more use of local labor and material should be used. Furthermore, no experiment has ever been made on a small revolving drum heater using wood fire. That is why it was thought advisable to try out a new kind of heater devised by Dr. R. C. Smith for the treatment of grain, and modified during the course of the tests by the writer with the idea of making it as simple and practical as possible. The aim was to devise equipment and work out an effective method of control within the reach of these small farmers, to be used in such places where labor is cheap and requiring the minimum amount of skill for its operation.

This paper is the result of two series of tests, one with the heater outdoors and the second in an electric oven in the laboratory. The aim of the latter was to determine the exact lethal temperatures for some of the commonest stored grain pests in the heater, and the temperature requirements of the newly devised apparatus.

REVIEW OF LITERATURE

In looking over the available literature relative to the control of stored grain insects, it was found that the French have been using heat for many years to control insects (Dean, 1914), and had devised special contrivances called insect mills for the heating of infested grain.

Webster, working in 1883 on the same problem of heat control, found that a temperature of 140°F. (60°C.) continued for nine hours literally cooks larvae and pupae of the Angoumois grain moth. A temperature of 130°F. (54°C.) for three hours proved fatal, as did also 120°F. (44°C.) for four hours, while 110°F. (38°C.) for six hours was only partially effective. It was also found that an exposure of eight hours to 150°F. (65°C.) did not impair the germination of wheat.

Lintner (1885), in the second report of the state entomologist of New York, said that a moderate degree of heat, 120° to 130°F., continued for a few hours would in all probability suffice to kill all the eggs, larvas, and pupae of the rust-red flour beetle infecting grain and flour, while a higher temperature, 150°F. (65°C.) or more, would be needed for the beetles.

Chittenden (1896), in his paper on insects injurious to stored grain, said that "until the adoption of carbon bisulphide as a fumigant, heat was relied upon as the best agent in the destruction of these insects. A temperature ranging from 125° to 140°F. (52° to 60°C.) continued for a few hours is fatal to grain insects, and wheatcan be subjected to a temperature of 150°F. (65°C.) for a short time without destroying its germinating power."

Dean (1913) gave a review of the literature available on heat for the control of stored grain insects up to 1911, from which most of the above material has been taken. As most of the work done previous to that date was concerned chiefly with the Angoumois grain moth, he worked out the practical control for all stored grain insects in flour mills by heat, and determined the fatal temperatures for these insects. In a specially devised apparatus under one inch of flour the confused flour beetle was killed when the temperature reached 120°F. (48°C.) after 12 to 15 minutes of gradual increase of temperature, starting at 80°F. Under one and two inches of flour in the oven, a temperature of 115°F. (40°C.) proved fatal to all the following insects in their various stages: confused flour beetle (Tribolium confusum), Mediterranean flour moth (Ephestia kuehniella), rice weevil (Calandra oryzae), and the cadelle (Tenebroides mauritanicus).

In the third set of experiments, under conditions comparable to what happens in a heat mill, the Mediterranean flour moth died when the temperature reached 118°F. (48°C.) after eight hours, 30 minutes of gradual rise from 87°F. The saw-toothed grain beetle (Silvanus surinamensis) died at 121°F. (50°C.) after nine hours, 15 minutes of exposure and the confused flour beetle at 122°F. (51°C.)after nine hours, 40 minutes.

From a series of heating tests done in mills the results obtained were found to be equivalent to the laboratory tests. So he concluded that in a mill a temperature ranging from 118° to 125°F. (48° to 52°C.) for 12 hours was sufficient to destroy all insect life.

During the same year, Gossard in Ohio reported the successful results obtained with heat in several flour mills.

Goodwin (1911), working in Ohio and Pennsylvania, also recommended highly the heat treatment for all the advantages offered over the other control.methods.

In 1911 the United States Department of Agriculture carried on some experiments on the control of mill insects in rice and peanut mills, and following the tests recommended also the heat treatment as a most efficient method in the control of insects in this class of mills.

Dean (1913, 1915) added again some further data obtained on heat in the treatment of mill insects at the 1912 meeting of the American Association of Economic Entomologists. These new data for the most part concerned the great extension of the heat system of insect control in flour mills and the satisfactory results obtained by the millers.

Chapman (1921) of the Minnesota Agricultural Experiment Station recommended at least 130°F. (54°C.) for the heating of grain, through a drier at the elevator; and in the case of unmoved grain as in a store-room, sacked material should be left exposed to that temperature until the center of the sack is at the same temperature as outside. A temperature of 124° to 154°F. (52° to 68°C.) for two hours has practically no effect on the germination of beans and this is about six times as long as is necessary to kill bean weevils. As wheat flour is ordinarily injured by a temperature ranging from 75°C. up, there is little chance of damaging the grain in treating it for insect pests, for the temperature necessary to kill these insects is well below any dangerous zone.

Cotton (1920) said that a temperature of 116°F. maintained for two hours will kill all adults, and a temperature of 124° maintained for two hours will kill all stages of rice weevil from egg to adult. Back (1922) gave some killing temperatures for weevils attacking peas and beans and stated that the adults are killed after four minutes of exposure to a temperature of 131°F. (55°C.).

Goodwin (1922) again pointed out that 120° to 130°F. (48° to 54°C.) killed as many if not most of the stored grain insects. Wheat treated at 150° F. (over 65°C.) germinated afterwards, and corn at 140°F. (60°C.) for two days germinated almost as well as untreated corn. Ordinarily, in a mill a temperature ranging from 122° to 140°F. (50° to 60° C.) is necessary to kill all insects there.

McDonald and Scholl (1922), working in the disinfection of cotton seed against pink boll worm in Texas, recommended the use of rotating driers, after having tested them several times; the seed was passed through a slanting rotating cylinder furnished with baffles to carry the grain. In order to shorten the length of exposure, the temperature of the drier was usually brought to a point above the desired temperature. According to these writers, the pink boll worm could be killed by heat without injuring the germinating power of the seed.

In studying the resistance of the rice and granary weevil to high and low temperatures, Back and Cotton (1924) found that their usual normal temperature was 50° to 60°F. (10° to 15°C.), while 95°F. (35°C.) was fatal to the rice weevil after nine days and to the granary weevil after 13 days. Both species died at 120°F. (48°C), after three hours and at 130°F. (54°C.) after 30 minutes.

Later the same writers (1928) found that the saw-toothed grain beetle was killed after an exposure of one hour to 125°F. (52°C.).

To kill both species of meal worms Tenebrio molitor L. and T. obscurus Fabr., Cotton (1929) recommended 130°F. (54°C.) for one hour.

Barber (1929), in treating ear corn by heat to control the larvae of European corn borer, submitted the ears to a temperature as high as 68°C. without any injury to the grain.

Dean and Schenk (1929) recommended anew the heat treatment which, although used chiefly by millers and large grain dealers, shows very promising possibilities for treating grain on a smaller scale as done in the revolving drums.

Swanson and Wagner (1930) stated that heating wheat to 140°F. (60°C.) for three minutes does not affect the milling and baking qualities of the product in any way that can be consistently detected by a group of cereal chemists.

In a series of experiments performed at Galveston, Texas, a power operated revolving drum-type of heater heated by steam was used. It required one hour to bring the drum up to the desired temperature before the grain was allowed inside.

The use of smaller machines to treat infested grain is becoming more and more general nowadays in mills and elevators, and there are many types on the market to meet the demands for a small drier or heater to dry and sterilize grain.

Some of these apparati are quite expensive and generally necessitate the use of steam to function, while others, although not so highly priced and of relatively low maintenance cost, require skilled labor for their proper manipulation. For the average Haitian and the small American farmers, neither of these two types of heaters would be of much interest; what they need is a cheap apparatus, easy to manipulate, even taking a little more time than the larger steam operated ones. The apparatus here presented has been devised for that group of people. If it proves to be of practical value in the field, an effort will be made to popularize its use among the small tropical farmers who have relatively small amounts of grain to treat.

From what has been said, it can be noticed that most of the investigators place the killing temperature for stored grain insects between 40° and 60°C. It will be also noticed that the temperature to which the insects are subject varies inversely with the length of exposure; the higher temperature being used with the shorter exposure. So in such an apparatus as revolving cylinders where the grain is exposed to heat for only three or four minutes, the temperature must be rather high. For instance Swanson and Wagner (1930) heated wheat through one of these drums where a constant temperature was maintained at 60°C. for three minutes. One must have in mind that the wheat entering the drum did not attain the temperature of the heater until at least one minute, so the actual exposure was ordinarily less than two minutes.

In addition, Chapman (1921) mentioned that grain passing through a drier must be heated to at least 54°C.

Back (1931) pointed out that a temperature of 120° to 130°F. (about 39°- 55°C.) for a short time, will kill all stages of grain infesting insects, without injuring the germinating quality of the grain.

Inasmuch as the apparatus that was going to be used was not one with constant temperature but rather one in which the temperature would fluctuate, the maximum set by Back which was the minimum of Chapman, i.e. 55°C. was taken as a basis for the tests to start with, and the effect of lower and higher temperatures along the course of the experiments in the field and at the laboratory was studied.

METHODS AND MATERIALS

The experiments on the heat control of store grain insects were carried on at the Field Insectary and in the laboratory of Kansas State College during the summers of 1930 and 1931. The field work consisted in testing the devised heater and the laboratory part was a series of experiments conducted with an electric oven in order to secure comparative data on the temperatures which will kill the stored grain pests by placing the grain with insects in it in a hot container as is ordinarily the case in treating infested grain by heat.

The Insects Tested

Three of the most common stored grain insects were selected and used in the check boxes as being of greatest importance in the handling of stored grain and easiest to secure in large numbers. These three insects were the confused flour beetle, Tribolium confusum Duval, the rice weevil, Sitophilus oryzae L. and the lesser grain borer, Rhizopertha dominica Fabr. These species, it is believed furnish an average representation of stored grain insects.

The Confused Flour Beetle. The confused flour beetle was the commonest of all three in the cultures established to provide specimens for checks, and so was available at any time. These insects thrive on a mixture of broken wheat and flour. Cultures were placed in 2 gallon jars in a room kept above 70°or 75°F. Once in a while a few drops of water would be added to keep up the moisture content of the jar.

The confused flour beetle is distributed all over the world and is very abundant in all parts of North and Central America. It is known as one of the flour beetles owing to its frequent occurrence in flour. It is a general feeder on starchy foods. It is probably the worst pest of prepared cereal foods, and is constantly found in granaries, mills, and storehouses and grain shipments.

The Rice Weevil. The rice weevil was quite difficult to obtain readily during the first summer. Several cultures were established under conditions that had proved suitable to their rearings in the past. They decreased very much in number with the advancing summer but during the summer of 1931 they were as abundant as the two other beetles.

The rice weevil also is found in all parts of the world where grain is used and is one of the very worst pests in stored grain. It is particularly abundant in warm countries where it breeds continuously and rapidly destroys all unprotected grain. In the Southern part of the United States, it causes tremendous loss to corn and is the commonest of the serious pests of commercial grain shipments. In some of the West Indies as Haiti for instance, it is found in practically all samples of Feterita, petitmil, and corn and causes considerable damage to other similar crops.

The Lesser Grain Borer. The lesser grain borers were nearly always available. They were just as numerous in their breeding jars as the confused flour beetles and kept reproducing all through the summer. So there was no difficulty experienced in securing these beetles whenever needed.

The lesser grain borer, more popularly known to many grain dealers as the "Australian Wheat Weevil", is one of the smallest beetles injurious to grain in the New World. It is widespread in the Gulf States and grain samples infested with this beetle are to be found in many large grain centers. They cause serious damage in warm climates attacking a great variety of grain especially in the tropics where they appear to have originated.

After these three beetles had been selected and used in the preliminary trials, it was noticed that there was a rather definite range of resistance to heat among them so it was decided to keep on working with them.

In addition to those insects, there were occasionally some other stored grain pests that either happened to be in the same grain samples before the tests or would be placed together with the three species mentioned in order to observe the comparative effectiveness of the tests when applied to the treatment of other stored grain insects. Some of them were:

The cadelle (Tenebroides mauritanicus L., the saw-toothed grain beetle (Oryzaephilus surinamensis L., and the Granary weevil Sitophilus granariae L. No special effort was made to secure data on these last beetles, only casual observations made in the laboratory tests being recorded.

The Heating Apparatus

The experiments at the Field Insectary were conducted with a heater of the revolving drum-type. The heat is furnished by a wood fire beneath the outer drum and the turning of the inner drum is done by hand. It was built especially to treat small quantities of grain at a time as most any farmer may have available and an effort was made to render its construction as simple as possible with the maximum of efficiency. The model used is a small experimental model. For practical work on farms, one of larger capacity would be used.

It consists essentially of an ordinary 15-20 gallon drum of the type used for shipping oil or powder insecticides, such as fish oil or calcium cyanide, made of thin galvanized iron. This first drum is enclosed in another 50 gallon oil or gasoline drum supported by a hollow iron spindle passing through the end center of both drums. The spindle is welded to the inner cylinder at the top and bottom of the latter, both ends pass through and come to rest upon the outer drum in circular holes cut out of the bases. One end of the spindle is furnished with a handle and the other is for support only. A lid on hinges locked by hooks closes the inner drum while the outer one may also be opened, the upper half being hinged to the lower. At one end of the hollow spindle is the rotating handle for turning the inner cylinder during the heating process. The spindle has two cleats at the end nearer the handle where a thermometer is inserted. This places it near the operator while he is treating the grain. Another thermometer was put in the inner cylinder with the grain. One can read the temperature of the inside at the drum on the stem of the thermometer placed in the spindle cavity where it is held in place by corks. The openings in the spindle inside the drum are covered with wire screen on both sides. This is the place where the bulb of the thermometer is placed in the spindle and it needs not be removed. The thermometer itself is prevented from any direct contact with the spindle by corks pierced through to hold the thermometer rigid, and breakage is prevented. Two or three baffles 2 - 3 inches in width are fastened to the inner drum by screws inside the cylinder to thoroughly mix the grain. They extend lengthwise to one inch of the ends of the cylinder in order to allow an easy flowing out of the grain when emptying the heater.

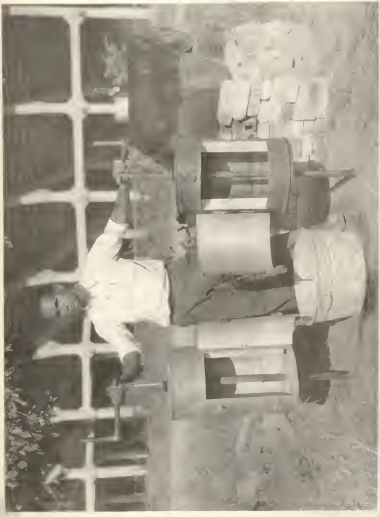
At the beginning of the experiment, a small oil drum was used for the inner cylinder. It was rather thick and heavy with the door cut in the middle but afterwards it was changed because of its weight, small capacity and great thickness of its wall, to a lighter and somewhat larger cyanide drum. This latter proved much more satisfactory than the first.

The outer drum is mounted on a firebrick stand with a cavity left in the center so as to be used as a furnace. The following illustrations give an idea of the apparatus ready to function.

Explanation of Plate I.

View of the two drums used for the inner cylinder, the better one at the right of the operator. The tub in the center was used for dumping the grain.

Plate I.



Explanation of Plate II.

View of the grain heating apparatus mounted on the brick base with the outer drum opened as in cooling off the apparatus.

Plate II.

Explanation of Plate III.

Near view of the end of the spindle near the handle showing the thermometer in position for reading the temperature of the inner drum. Note that the thermometer is held in place by corks.

Plate III.

Explanation of Plate IV.

View of the apparatus in operation, the inner cylinder being rotated slowly while the outer drum is closed.

Plate IV.

The principle applied in this apparatus is to have the cylinder containing the grain not in direct contact with the wood fire but heated merely with the hot air circulating in the space between the two drums.

If it were not so, when heating the grain there would be a greater chance of scorching the seeds that would come in contact with the walls of the container, while those nearer the center of the mass would not be evenly heated. That is exactly what happened in a stationary heater tried out in Haiti by Dr. R. C. Smith for stored grain control. The apparatus consisted of an inner metal pan on which a layer of grain had been placed within a box type container with ventilators in the lid and placed on a wood fire. The temperature near the outside of the grain rose rapidly while the center would still be cool. Then all the insects in the grain gradually moved toward that center until they would collect in a little nucleus like a bee cluster. To get any control it was necessary then to heat the grain to a temperature that would scorch the grain in contact with the wall of the heater.

This does not mean that a rotating device would eliminate any danger of scorching the grain, for when the container is hot, there are evidently the same precautions to take, but the indirect contact reduces such danger and makes the control of the amount of heat applied to the heater easier. Two heavy bars of railroad rails were laid lengthwise in the bottom of the outer cylinder to prevent the apparatus from rolling off the stand while opening the cylinders.

The Fire

The wood fire was maintained with any kind of wood which was available. It consisted mostly of boards obtained from old boxes or barrels. Only a few pieces at a time were placed in the furnace but it was rather difficult to obtain a constant fire as one may realize.

Grains Used

Four kinds of grain were used in these tests: barley, corn, popcorn and wheat. Only a small amount of the first three could be obtained for testing. Besides, the corn was so damaged by insects that it was feared the germination tests could not be carried out. Wheat then was the most used grain as being the most available at the Kansas State College Milling Department and also because of the difficulty of finding the insects attacking each kind of grain. Furthermore, most of the stored grain insects of considerable interest are found in wheat and their destruction in such a grain could be taken as a basis for similar control in other kinds of seeds.

Check Boxes

In order to determine the best ways of using the check boxes in that type of apparatus, a variety of boxes was used: the small cardboard pill boxes, small salve boxes, and larger salve boxes with screen tops and bottoms. As the one ounce size of the salve boxes proved to be better than the other types, they were used in most of the tests.

The number of insects placed in the check boxes varied to some extent. In some experiments samples of infested grain with live insects in them were used, in others the insects were put in uninfested grain in the check boxes. The results obtained were not different in so far as the action of the heat was concerned for as soon as the temperature began to rise, the insects hidden inside the kernels would come out and run about just the same as they do when placed with unbroken kernels. However, due to the difficulty of making the count of beetles with unbroken grain after the operations to determine the percentage of control, the last method was resorted to in most cases.

Usually five specimens of each one of the confused flour beetle, the rice weevil and the lesser grain borer were placed in the one ounce tin salve boxes filled with the same kind of grain being treated in the apparatus.

THE FIELD WORK

Aims

In running the tests, the following points were considered:

(a) Determine the temperature necessary to kill all kinds of insects attacking stored grain with the heater and especially the three species of insects used in these tests.

(b) Determine the length of time necessary to reach the killing temperature.

(c) Determine the length of exposure necessary to cause the death of the insects.

(d) Determine the effect of the temperature upon the germination of heated grain.

(e) Find out any improvement that could be made to this type of heater as devised at the beginning of the investigations and the general ways of operating the apparatus to make it work satisfactorily in the hands of farmers or small grain dealers.

The Experiments

In these experiments, three to five gallons of grain were placed in the container with a few check boxes containing specimens of the three insects chosen, and put in the outer drum with the fire going on. By rotating slowly and almost constantly the inner cylinder, an even mixing up of the grain is secured. Comparative readings of the temperature in the container were taken by the thermometer placed in the spindle and from the grain itself in which another thermometer was placed, as said before.

Results

The following table gives the results of the tests conducted with the heater.

The first column at the left in Table I gives the serial number of the tests, the second the temperature at the spindle when the grain was removed from the apparatus, the third is the exact temperature of the grain at the time the heating was stopped. The fourth column indicates in nearly all cases the length of time necessary for the grain to reach the temperature indicated in the third column, starting from the ordinary temperature (about 30°-35°C.). The fifth column together with the sixth and seventh give the percentage of dead beetles found in the check boxes after the operation, the eighth indicates the per cent of germination, and the ninth the kind of grain used.

Table I. Summary of the Experiments run in the Heater in the Field and the Results

Test No.	Temp. at Spindle	Temp. of Grain	Time ex-posure	Insect: CFB % dead	Insect: RW % dead	Insect: LGB % dead	Germi-nation	Grain
1	50°C.	58°C.	20 min.	---	---	---	50 %	Wheat
2	50	58	18	46	57	---	45	Corn
3	50	52	20	50	40	---	30	Corn
4	54	59	25	100	100	100	43	Corn
5	54	57	12	100	100	100	33	Corn
6	52	56	15	100	100	100	49	Corn
7	60	56	2	---	---	---	69	Wheat
8	55	57	15	---	---	---	72	Wheat
9	55	60	8	---	---	---	63	Wheat
10	55	61	7	---	---	80	75	Wheat
11	55	52	10	50	100	82	100	Popcorn
12	52	57	18	50	100	45	94	Popcorn
13	55	58	25	100	100	74	96	Popcorn
14	54	56	18	100	100	83	92	Barley
15	57	52	3	0	0	0	90	Barley
16	54	54	30	100	100	92	69	Wheat
17	58	55	10	100	100	96	61	Wheat
18	55	54	17	100	100	100	71	Wheat
19	57	53	15	100	100	79	79	Wheat
20	56	53	10	100	100	79	80	Wheat
21	56	53	15	100	100	84	81	Wheat
22	60	53	15	100	100	8	70	Wheat
23	56	57	25	100	100	80	72	Wheat

Table I. Continued

Test No.	Temp. at Spindle	Temp. of Grain	Time ex-posure	Insect CPB % dead	Insect RW % dead	Insect LGB % dead	Germi-nation	Grain
24	55°C.	53°C.	15 min.	100	96	100	83 %	Wheat
25	52	53	25	90	100	45	83	Wheat
26	54	54	15	32	68	20	72	Wheat
27	58	54	12	75	100	44	69	Wheat
28	55	55	20	100	100	84	86	Wheat
29	55	55	20	60	84	72	81	Wheat
30	57	56	20	60	68	72	80	Wheat
31	54	54	25	85	100	85	71	Wheat
32	55	54	15	72	100	75	80	Wheat
33	56	58	25	100	100	64	86	Wheat
34	55	54	10	52	100	32	73	Wheat
35	52	58	19	100	100	84	67	Wheat
36	49	55	19	100	100	60	79	Wheat
37	53	59	15	100	100	100	77	Wheat
38	55	60	13	100	100	100	79	Wheat
39	60	60	20	100	100	100	80	Wheat
40	58	58	12	100	100	64	79	Wheat
41	56	67	28	100	100	100	72	Wheat
42	65	65	17	100	100	100	80	Wheat
43	55	55	15	100	100	100	74	Wheat
44	57	61	19	100	100	100	79	Wheat
45	55	57	15	100	100	100	76	Wheat
46	56	58	13	100	100	100	77	Wheat
47	58	57	9	100	100	96	75	Wheat
48	58	57	10	100	100	96	68	Wheat

Table I. Continued

Test No.	Temp. at Spindle	Temp. of Grain	Time ex-posure	Insect CFB % dead	RW % dead	LGB % dead	Germi-nation	Grain
49							73 %	Wheat, check untreated
50							44	Corn, check untreated
51							93	Barley, check untreated
52							98	Popcorn, check untreated

<u>NOTE:</u>

CFB = Confused Flour Beetle
RW = Rice Weevil
LGB = Lesser Grain Borer

Preliminary Trials. The purpose of the preliminary trials was merely to test the operation of this heater and to determine the methods to be used in later experiments.

As the conditions under which the tests were carried, varied to quite an extent, they must be explained individually in order to understand the results properly.

The first three trials of the apparatus were of little importance. In these trials the outer drum was set on a very low stand of four stones to hold it still and afford enough space between them for a low wood fire. The inner cylinder used (as also in many of the following tests) was the small and heavy oil drum spoken of before which had a capacity of about 15 gallons.

Three gallons of grain were used at each of these three tests. For the first trial, two gallons of crank case oil were poured into the outer drum to hold the heat and thus make it even and to prevent overheating the outor drum. But as there was a small amount of water in the larger cylinder with the boiling oil, most of the grain in the heater became practically soaked with oil. The use of oil was discontinued. Only one thermometer was kept constantly in the grain cylinder: the one in the spindle.

It was thought that this thermometer would indicate in a more or less accurate manner the air temperature within the grain container which would be approximately the same as that of the grain. This would simplify very much the matter of recording the grain temperature due to the difficulty of keeping a thermometer in direct contact with the grain at all times. But it became necessary to record simultaneously and compare with the first, the exact grain temperature for there were in many cases, differences in the readings caused by many factors which will be considered later.

A third thermometer was placed in an orifice on top of the outer drum in these trials to record the temperature of the air circulating between the two cylinders. But when it was noticed that such temperature was far above the range of the ordinary Centigrade instruments used, the thermometer was removed.

The Other Tests. Most of the other tests ran more or less uniform with two thermometers indicating the temperature at the spindle and in the grain.

The grain was placed in the container with the check boxes, the thermometer placed in a wooden case in the grain and the cylinder set over the fire while the inner drum was rotated constantly. Readings of temperatures were made every five minutes and when the desired temperature was reached, the inner cylinder was removed, the grain dumped and the apparatus was ready for another test.

Comments on the Experiments. Three gallons of wheat with no check boxes were used in the first trial, the purpose being to get an idea of the length of time required to bring the temperature up to 55°C. A Fahrenheit thermometer was used and an error slipped in when the mark of 122° (50°C.) was mistaken for 131° (55°C.) which was desired. After 20 minutes the spindle thermometer recorded 122°F. (50°C.). A thermometer inserted in the grain showed 58°C. This was by no means exact as the hot air coming from the heated walls of the iron drum passed around the bulb of the thermometer.

Three gallons of corn were placed in the heater for tests II and III. In the tin salve box check boxes, confused flour beetles and rice weevils only were used.

As the drum was only occasionally rotated in the second test, there were some very marked differences in the percentage of insects killed in the check boxes, some had all the insects in them dead, some had all insects alive and others with some dead and some alive, showing the uneven heating caused by the uneven mixing up of the grain.

In the third, a more constant rotation gave better results. The temperature of the grain in the two tests was taken by scooping some of it in a cardboard box and inserting the thermometer through the grain.

Following these preliminary trials the whole apparatus was mounted on a fire brick stand and the outer drum weighted down by placing pieces of two heavy iron railroad rails in the bottom to prevent rolling over. The Fahrenheit instruments were replaced by Centigrades as these are preferred in scientific work. On these each mark indicates a degree instead of two degrees as on the Fahrenheit thermometers.

In Tests IV, V, VI, three gallons of corn were used in each and 8 ounce screened salve boxes were used for check boxes with lesser grain borers in addition to the two other beetles used in the previous tests as check insects. A low fire was used for the fourth and a rather strong fire in the fifth and sixth tests.

During the seventh test, the outside air temperature was so hot that the thermometer in the spindle of the drum registered 40°C. when not on the fire. After placing the cylinder on the fire, the mercury rose immediately and after two minutes it reached 50°C. At this rate of increase of temperature, it was useless to try to take the temperature of the grain by the usual scooping method as the mercury was still going up. In view of the inaccuracy of the results obtained, the apparatus was removed from the fire which evidently was too strong.

Check boxes were left in the wheat exposed to the hot sun for 15 minutes and upon examination, all the rice weevils were found dead.

As the same conditions were about to prevail for the eighth test, the amount of fire was reduced and the apparatus was rotated more rapidly. The temperature went down first, the grain absorbing the heat from the air in the cylinder and then went up again as the fire increased.

In the ninth, tenth and eleventh tests, some cardboard pill boxes were used and as they proved much less satisfactory than the fast heat conducting tin boxes, they were discontinued. In the tenth and eleventh tests, check boxes were tried, filled up with infested material in which plenty of live insects of the three species occurred. This would represent a little better the actual conditions of insects in infested grain. But the results were not different from those obtained by using uninfested grain with live insects for the beetles hidden within the kernels or packed material became active and ran about when the temperature began to rise. However, it was somewhat difficult to count the beetles and very hard to arrive at an exact percentage of killing as there were both dead and live insects in the infested grain. In such cases, only complete or no control could be determined so it was not so good. In Tests IX and

X three gallons of wheat, while in XI five gallons of popcorn were used.

Five gallons of popcorn were used for Tests XI, XII and XIII. In the twelfth, it was decided to put a thermometer with the grain itself. It was fixed in a wooden case with only the bulb end exposed. This prevented the thermometer from breaking. The readings were also more accurate as both grain and thermometer were kept moving constantly, the temperature indicated would be nearer being exact than by any other means.

In the twelfth test, in order to get an idea of the effect of the air temperature on the heater, the inner drum was laid on the hot soil with the grain on it and left there for fifty minutes before setting it on the furnace. Check boxes containing whole grain and only live insects were used for Test XII and infested grain with dead and live insects for Test XIII.

For all the rest of the tests, checks with live insects only were used. Five of each species were placed in five boxes.

Barley was used in Tests XIV and XV, seven gallons for each one. In XIV, the grain in the heater on the ground was left exposed to the sun for 15 minutes before placing it over the fire; the air temperature being at 42°C. it was thought desirable to find out how much the air temperature would heat up the grain in that case. In XV the grain was heated without checks in it and when the temperature reached 52° the check boxes were placed in for three and seven minutes. In so doing, it was thought possible to have some slight indication on the length of exposure necessary to kill the insects at a certain temperature. But this could not be determined as the temperature kept going up during the time. Following this test, wheat alone was used in all the others, five gallons of grain being used in each case unless otherwise stated.

In the sixteenth test, it happened that the thermometer moving with the grain caught between the wall and one of the baffles of the drum. It is needless to say that the difference between the readings of the thermometer and the one at the spindle became quite evident and this explains some of the differences appearing in other tests. In Tests XVIII to XXII, only three gallons were used. The conditions prevailing for these tests were very much the same except the amount of fire for each test which caused the grain to heat up faster or slower. In Tests XXVIII to XXX, three and one-half gallons of wheat were used.

In the light of the results obtained in previous experiments it has become evident that the heavy drum used for the inner cylinder was unsatisfactory so it was replaced by another one - a calcium cyanide drum, lighter and of larger capacity with which all the other tests were run.

The following experiments were carried on in the summer of 1931, most of them being of higher temperatures than the former ones. In Tests XXXVI to XLV, six gallons of wheat were used.

During tests number 35 to 38, there was a strong wind blowing. Originally the end of the hollow spindle was corked but for these tests, the cork at one end was left out so there was an air draft passing in and cooling off the thermometer. As a result, there was a constant marked difference between the temperature of the grain as registered by the thermometer moving with the grain and the readings at the spindle, the latter being lower. The cork was put back for Nos. 39-43, and taken off for Nos. 44 to 48 which were run on less windy days. The effects of the presence or absence of the cork can be noticed in Table I, tests number 35-48.

The series of tests run during June 1931 were mostly high temperature tests, the purpose of which was to determine more accurately the fatal temperatures necessary to control the lesser grain borers. However, both rice weevils and confused flour beetles used last year with the lesser grain borers, were also used in these tests.

Discussion of Field Work

From Table I it can be readily seen that the rice weevil is the less resistant to heat and the easiest to kill of the three beetles, while the lesser grain borer is the hardest to destroy by heat. The confused flour beetle ranks next, being much more resistant than the rice weevil and not so much as the lesser grain borer. In some cases, the rice weevil has been killed after the temperature of only 52°C. had been reached and the lesser grain borer was not killed at a temperature of 57° while the average temperature for their destruction seems to range between 55 and 58°C. One of the most important factors to account for the variations of the results obtained by submitting the insects to the same temperature is the length of exposure. This is a rather delicate point to regulate as one cannot always have a uniform fire that would raise the grain temperature to a certain degree within a certain time. This cannot be avoided in most of the cases as the drum will heat faster or slower according to the air temperature, grain humidity, amount of fire, kind and amount of grain, rotation of the cylinder, etc.

But an effort was made to overcome at least a part of these difficulties and have the grain temperature reach 55°

or 56° after 15-20 minutes. The best way to do it is to start with a good fire, rotate the cylinder continually and when the temperature reaches 53° or 54°C. lessen the amount of fire and keep rotating the drum until the temperature passes 55°. Or by using small pieces of wood, one can make a fire which will be pretty strong at the beginning of the test and will gradually become weaker as the drum temperature goes higher. So at the end, there will be almost no rise of temperature caused by the fire. By opening the outer cylinder, one can in a certain measure, control the heat but if the air is too hot inside the grain container, there are some chances to have difficulties in cooling off rapidly the cylinder.

Amount of Grain Used. The amount of grain used also had a good part to play in the length of time required for heating the grain to a desired temperature. It was found that a quantity of grain as much as half the capacity of the cylinder could be used with good results providing that the baffles moving the grain be wide enough to permit thorough mixing up of the grain. In the later tests (31-48) four-inch baffles were used which gave more satisfactory results than the two-inch baffles used in the other tests.

Outside Temperature. The air temperature, which varied very much during the tests has a strong influence on the heating. To take advantage of it, it would be better to work during the hot weather, leaving the grain first exposed to sun rays before heating it in the cylinder. The grain would then be at a temperature averaging 35-40° what is already a good step toward the required temperature. When the cylinder itself is heated by the sun rays and the air temperature inside tends to raise up, a few rotations of the cylinder suffice to bring it down near the grain temperature. In such cases, the readings would go in a fashion like that 50° - 55°, 50° 48° and back, 50° 42°, 56°.

Grain Moisture. The humidity of the grain although not as important in these tests as the other factors must also be considered, for the germination of the grain is directly connected with the amount of moisture present. If the grain is too moist before the heating, the chances of injuring its germination power increase very much, due to the steaming, (Chapman, 1921) (Barber, 1929) while if the grain is very dry, the heating may reduce the moisture content somewhat. But in general, grain with a moisture content about the average (12-13%) was used so one could not find much variation in the tests caused by the difference of humidity. Furthermore, the moisture contents of any of the grains before or after making the tests was not determined.

Kinds of Grain Used. So far as the kind of grain used is concerned, the main factors which might cause variations in the test are the size of the kernels and subsequently the resistance to heat penetration, besides resistance of the germ to heat. The wheat kernels are comparatively small so it does not take long for the heat to penetrate them. The corn kernels on the contrary, are quite large and require a longer exposure to reach a desired temperature.

Many of the grain pests hide inside the kernels but it was frequently observed that with the rise of the air temperature, the insects leave their burrows hurriedly to come out and walk through the grain, where they are more easily killed. In some cases, though they may stay inside especially in highly infested grain like wheat infested with lesser grain borer. The kernels are then packed into small masses of broken and infested seeds stuck together and in such a refuge the insects may escape unaffected.

Conclusions of Field Work

After having worked on the devised heater for two summers, and run more than fifty tests with it, the writer feels justified in saying that such an apparatus will work in a practical way.

There are some advantages which would appeal to people who have the problem of stored grain insect control.

1. It is cheap and can be made in most any small community, on account of its simplicity, out of materials largely available for little or no expense.

2. It is easy to operate and most any farmer or average laborer could operate it with a little preliminary instruction and practice.

3. It gives a 100 per cent "kill" and is an efficient control for stored grain insects besides drying the grain.

4. Temperatures necessary to kill the insects do not affect the germinating power of the seed so it is a safe method, if those temperatures are not appreciably exceeded.

5. It is economical for the source of heat used is an ordinary wood fire and in places where wood is cheap, the cost of operation is low.

On the other hand there are some disadvantages in using such a heater for insect control.

1. Being of small dimensions only a limited amount of grain can be treated at a time rendering the process a rather lengthy affair. This can be counteracted by making a larger type heater or one in which the grain passes through the heater continuously.

2. The wood fire being inconstant, it follows that there must be some precautions to take against attaining too high a temperature and scorching or burning the grain by a

too strong fire.

3. When the drum is hot, it is difficult to handle it without getting burned. Two men could do it more easily and satisfactorily than one. The size of the heater could be increased, using a 50-gallon drum for inner cylinder and a larger one for outer cylinder, or drums ten or more feet long could be used to make of it a continuous type being fed at one end and dropping the grain at the other. It could be made to slant with baffles inside; by regulating the inclination, the grain could be allowed to be heated only for a short time, three to four minutes at 58°C.

But there are some points to consider before venturing to recommend and extend its use.

First of all, the type of person to use such an apparatus. In this country (United States) the average farmer ordinarily could not give the time necessary to manipulate such a machine so there would not be much use for it on his farm. But in the tropics where labor and wood are cheap, the heater might do very well.

It is evidently advantageous to try to use the apparatus when the outside temperature is rather high so as to have the grain already quite warm when starting to treat it. In the tropics where the mild climate all year round keeps the air warm, such an apparatus should be of practical application for the average small grain producer or grain dealer. It would be advisable to treat the grain with the heater at harvest to dry it and to kill the insects. Then, if stored in tight containers, there would be no damage from insects.

LABORATORY EXPERIMENTS

Concurrently with the Field experiments, a series of laboratory tests was also carried on in order to obtain comparative data under more uniform conditions of heat than with a wood fire. They consisted in subjecting the insects to different temperatures in an electric oven for certain lengths of time. Since the temperature of the oven was almost constant during each test, there was a better opportunity of ascertaining accurate data on the lethal temperatures of the various species than with the use of the heater. It was endeavored to have the conditions for these tests as uniform as possible although there were some variations of temperature that could not be avoided in opening and closing the doors of the oven.

Methods and Materials

A certain number of open check boxes containing insects in wheat was placed at the same time in the oven at a given temperature. At definite intervals, usually every minute or so, a box was taken out and the insects examined to see after how long an exposure they had begun to die. Each check box contained one thickness of grain with the insects on the grain.

Results

Table II shows the results obtained with the confused flour beetles, the rice weevils and the lesser grain borers. Each number represents a box with five insects of each species.

Table II. Results of Electric Oven Experiments on the Three Species of Grain Insects at Minute Intervals.

August 1930

Experiment No.	Time	Temp. In	Temp. Out	RW	CFB	LGB
1	1 min.	49°	50°	5a	5a	5a
2	2	49	51.5	5a	5a	5a
3	3	49	53	5a	5a	5a
4	4	49	54	5a	5a	5a
5	5	49	56	5a	5a	5a
6	6	49	57	5a	5a	5a
7	7	49	56	4a 1d	5a	5a
8	8	49	55	2a 3d	5a	5a
9	9	49	54	5d	5a	5a
10	10	49	53.5	5d	5a	5a
11	11	49	53.5	5d	3a 2d	5a
12	12	49	53.5	5d	5d	5a
13	13	49	53.5	5d	5d	5a
14	14	49	52	5d	5d	5a
15	15	49	52	5d	5d	5a
16	16	49	52	5d	5d	5a
17	17	49	53	5d	5d	5a
18	18	49	54	5d	5d	5a
19	19	49	54	5d	5d	3a 2d
20	20	49	55	5d	5d	5d
21	21	49	55	5d	5d	5d
22	22	49	55	5d	5d	5d
23	1	50.5	51.7	a	a	a
24	2	50.5	52	a	a	a
25	3	50.5	52	a	a	a
26	4	50.5	52	a	a	a
27	5	50.5	52	a	a	a
28	6	50.5	53	a	a	a
29	7	50.5	53	a	a	a
30	8	50.5	53	3a 2d	a	a
31	9	50.5	54	1a 4d	a	a
32	10	50.5	55	5d	a	a
33	11	50.5	55	5d	a	a
34	12	50.5	55	5d	a	a

Table II. Continued

Experiment No.	Time	Temp. In	Temp. Out	RW	CPB	LOB
35	13 min.	50.5°	56°	5d	2a 3d	a
36	14	50.5	56	5d	5d	a
37	1	51°C.	51.5°C.	5a	5a	5a
38	2	51	52	5a	5a	5a
39	3	51	53	5a	5a	5a
40	4	51	54	5a	5a	5a
41	5	51	56	5a	5a	5a
42	6	51	57	5d	5a	5a
43	7	51	58	5d	5a	5a
44	8	51	58	5d	3a 2d	5a
45	9	51	58	5d	5d	5a
46	10	51	58	5d	5d	5a
47	1	53	53	a	a	a
48	2	53	54	a	a	a
49	3	53	54	a	a	a
50	4	53	53	a	a	a
51	5	53	54	a	a	a
52	6	53	54	2a 3d	a	a
53	7	53	55	5d	a	a
54	8	53	55	5d	a	a
55	9	53	55	5d	a	a
56	10	53	56	5d	a	a
57	11	53	55	5d	a	a
58	12	53	54	5d	4a 1d	a
59	13	53	54	5d	5d	a
60	14	53	54	5d	5d	a
61	1	55	55	a	a	a
62	2	55	55	a	a	a
63	3	55	56	a	a	a
64	4	55	55	a	a	a
65	5	55	55	2a 3d	a	a
66	6	55	56	1a 4d	a	a
67	7	55	54	5d	a	a
68	8	55	55	5d	a	a
69	9	55	55	5d	a	a
70	10	55	55	5d	a	a
71	11	55	56	5d	a	a

Table II. Continued

Experi-ment No.	Time	Temp. In	Temp. Out	RW	CFB	LGB
72	12 min.	55°	56°	5d	a	a
73	13	55	56	5d	a	a
74	14	55	56	5d	1a 4d	a
75	15	55	56	5d	1a 4d	a
76	16	55	56	5d	1a 4d	a
77	17	55	56	5d	1a 4d	2a 3d
78	18	55	56	5d	1a 4d	5d
79	19	55	56	5d	1a 4d	5d
80	20	55	56	5d	1a 4d	5d
81	1	55	56	a	a	a
82	2	55	56	a	a	a
83	3	55	56	a	a	a
84	4	55	55	1a 4d	a	a
85	5	55	55	5d	a	a
86	6	55	55	5d	a	a
87	7	55	54	5d	a	a
88	8	55	55	5d	a	a
89	9	56	56	5d	a	a
90	10	56	55	5d	a	a
91	11	55	55	5d	a	a
92	12	55	55	5d	a	a
93	13	55	55	5d	a	a
94	14	55	55	5d	1a 4d	a
95	15	55	54	5d	5d	a
96	16	55	55	5d	5d	a
97	17	55	55	5d	5d	2a 3d
98	18	55	55	5d	5d	1a 4d
99	19	55	55	5d	5d	5d
100	20	55	55	5d	5d	5d

NOTE:

Room temperature 35°C.

RW = Rice weevil

CFB = Confused flour beetle

LGB = Lesser grain borer

Discussion

It may be seen from the above table that there is a marked difference between the resistance of the three beetles to heat; the rice weevil is the first to succumb, the confused flour beetle was more hardy and the lesser grain borer being much more resistant than the other two.

The rice weevil appears to die at 55° after five to eight minutes; the confused flour beetle after 15 minutes and the lesser grain borer after 17-20 minutes. These relative proportions were found to be correct in the field experiments as shown in Table I and were of value in guiding the latter experiments for obtaining certain data on length of exposure necessary to kill the lesser grain borer.

In all the tests done in the laboratory in the incubator, it was endeavored to have the conditions as uniform as possible, but, as it can be seen by reference to the tables above, there was some variation of temperature which could not be avoided when one is opening the door to manipulate the check boxes. The amount of wheat used was always the same, one-third of an ounce or rather one thickness of wheat in a check box.

In a few cases, the insects which came in contact with the hot salve box could not get back on the kernels where they ordinarily stay and died in a few seconds.

But generally the insects were on the kernels right after the beginning of the heating and kept running about there for six to eight minutes (55°). Then they would be seen to slow down and finally kept still until they died, which happens normally some 15 minutes later for the confused flour beetle.

The lesser grain borer stopped running about at the same time as the confused flour beetle but they revived after a 15 minute exposure. But when left for 18-20 minutes they did not revive.

GERMINATION TESTS

Standard germination methods used by the State Seed Laboratory were used in these tests to determine the effect of the heat on the germinating power of the grain tested.

Two lots of 100 seeds each were taken from each sample treated and spread on wet blotters, then the blotters placed on trays in the incubator. The wheat and barley (were) germinated in a standard germinating chamber at a constant cold temperature of 20°C.

The corn and popcorn were placed in another germinator with alternating cold and warm, 35°C. in the day time and 20°C. at night. The counts were made seven days after the seeds were placed in and the final check the next day.

The results of the tests are also shown in Table I.

There was no appreciable difference between the germinating power of the untreated sample and the grain heated to a temperature as high as 60°C. for a few moments. So the heat necessary to destroy the insects had no appreciable effect on the germination power of the grain.

SUMMARY AND CONCLUSIONS

I. These experiments indicate that:

A. Starting with a cold drum.

1. With a low fire.

An exposure of 25 minutes with a temperature of 58° at the spindle killed all confused flour beetles, the rice weevils and the lesser grain borers in wheat, corn and popcorn.

2. With a medium fire, 20 minutes gave the same temperature that was lethal to the insects.

3. With a strong fire - 15 minutes was enough to reach the same temperature.

B. Starting with a hot drum.

1. With a low fire, 20 minutes of exposure brought the grain up to the same temperature.

2. With a medium fire, 15 minutes was necessary.

3. With a strong fire, 13 minutes gave a temperature of 58° which killed the beetles.

C. In all the experiments it was necessary to have an exposure above 55° for about three minutes before all the insects were killed, and as the temperature went on increasing, the exposure was lethal to the lesser grain borer, the most hardy of the three.

D. There was in some cases, some difference between the temperature of the grain and the temperature registered by a thermometer placed in the spindle and whose bulb is in direct contact with the air inside the grain container when the stem is exposed outside. The differences were not constant and were controlled by the proper manipulation of the apparatus.

E. Seed left exposed for such a length of time germinated as well as untreated seed. When the temperature goes above 65°C. there is a decrease in the percentage of germination.

F. Laboratory tests ran with the same beetles showed that the rice weevil is killed after five to eight minutes of a constant exposure to a temperature of 55°C, the confused flour beetle after 15 minutes and the lesser grain borer after 18 to 20 minutes.

G. The devised heater is of practical application in communities where labor and material such as wood are cheap for besides controlling the insects, it also dries the grain. In other places its application would be probably restricted unless modified.

H. The size of the apparatus could be increased. In so doing the amount of grain treated in a given time would also be increased.

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