THE EFFECTIVENESS OF PYRENONE GRAIN PROTECTANT AGAINST FOUR SPECIES OF GRAIN INFESTING INSECTS WHEN APPLIED TO SHELLED CORN AND SORGHUM

by

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INTRODUCTION

Stored grains have been known to be subject to the ravages of certain insects for thousands of years. As more knowledge has been built up through the years, new and better methods of controlling these insects have been developed.

The struggle of man against the insects in stored grain is still going on, even with the development of many new materials that are effective in ridding grain of the insects. The problem of insects in stored grain is one of major importance because of the fact that grain is one of the main foods of the people of the world, and because the insects take such a large percentage that would otherwise be used as food for man and his animals.

The fact that a large amount of the grain produced in the world each year is destroyed by insects is shown by Cotton (1948). He stated that the total loss in caloric value of the grain lost to insects would supply a major part of the diet of 360,000,000 adult persons for one year. This same loss would appreciably supplement the diet of 1,000,000,000 adult persons whose diet is now deficient.

Insects destroy at least five percent of the cereal grains produced in the world. A survey made in 1947 by the Food and Agriculture Organization of the United Nations showed that the total loss in 29 countries was 25,750,000 tons, of which 50 percent could be attributed to insects.

The United States suffers a large amount of loss. Losses as high as 10 percent of the wheat in one season have been recorded in the Great Plains area, and stored corn in the deep South may be destroyed at the rate of nine percent per month, according to Cotton and Ashby (1952).

A new product has recently been introduced to the grain industry that is designed to prevent insect infestation in stored grain before it begins. This is the most practical way of controlling insects in the grain if it may be worked out economically. This new product combines pyrethrins and piperonyl butoxide with an inorganic dust carrier and is known as Pyrenone Grain Protectant.

This material is used to give the stored grain a protective coating of insecticidal dust and protect it from insect infestation. The use of dusts to protect stored grain against insect infestation is not new, as pointed out by Cotton and Ashby (1952). Inert dusts have been utilized for this purpose, but their efficiency decreases as the moisture content of the grain increases. Poisonous dusts act on the insects regardless of the moisture content, but because of the chances of poisoning man or animals as they consume the grain or its products, these dusts have not been regarded as practical.

Pyrenone Grain Protectant has as its insecticidal components, a combination of chemicals that are toxic to insects, but relatively harmless to warm blooded animals. The pyrethrins and piperonyl butoxide, the combination of which is known by the trademark "Pyrenone," are widely used in the food industry because of their low order of toxicity to warm blooded animals. For this reason, the grain protectant may be used on grain with relatively little danger to man and animals and still utilize the high toxicity of the materials to insects.

The grain protectant has been widely tested and used in the past few years. Even though it has enjoyed a high degree of popularity, many things still need to be known in order that the protectant may be used with the maximum effectiveness to protect stored grain.

The grain protectant was designed for use on all grains other than wheat. Corn and sorghum are two of the major cereal grains other than wheat and were selected for use in this experiment.

The purpose of the work reported on in this thesis was to study the effectiveness of the protectant on shelled corn and sorghum at different levels of moisture against four species of grain infesting insects. Since the protectant may be used on all grains other than wheat, it was desired to know if it was equally effective on different grains, or if each type of grain exerted an effect on the protectant as measured by its effectiveness in protecting the grain from insect damage. The work was carried out in the Department of Entomology at Kansas State College of Agriculture and Applied Science with the assistance of the Department of Milling Industry and the U. S. Industrial Chemicals Company of Baltimore, Maryland.

REVIEW OF LITERATURE

The control of insects in stored grain using dusts is not a new idea. Many types of dust, both poisonous and non-poisonous, have been used in attempts to protect grain in storage. Parkin (1944) reported the use of flint, felspar, limonite, and anhydrite against the granary weevil and also observed that the saw-toothed grain beetle was the most susceptible to the action of the dusts.

Cotton and Ashby (1952) stated that other inert dusts have been used to control stored grain pests. They reported that dusts of finely divided silica gel, rock phosphates, precipitated chalk, magnesium and aluminum oxide have been successfully used. These dusts may be used at the rate of one part dust per 1000 parts of grain by weight if the particle size is one micron or less.

The mode of action of the inert dusts is not clearly understood as pointed out by Parkin (1944). There are three possible effects that the dusts may have on the insects. The first is the adhesion of the dust to the body surface, and especially to the intersegmental membranes and joints of the limbs. It is believed that the presence of the dust in these locations on the body of the insect cause a hindrance to movement on the part of the insect. This restriction of movement may affect copulation and oviposition. Although the dusts may restrict the spread of the insects by acting in this manner, the action cannot be regarded as the cause of death.

A second possible action of the dust is the complete stoppage of the mouthparts. Should this occur, starvation would result. This is not regarded as probable because dusted weevils succumb more rapidly that undusted weevils in the absence of food.

The third and most probable explanation of the action of dusts is the interruption of the continuity of the water retaining lipoid layer of the cuticle by adsorption. This action allows evaporation to occur and the insect dies of desiccation.

Poisonous dusts have also been used to control stored grain insects. These dusts act independently of the moisture content of the grain according to Cotton and Ashby (1952). They stated that lindane is effective at one part per million and DDT is effective at 15 parts per million. The greatest drawback to the use of poisonous dusts is the possible toxic effects on the animals that utilize grain for food. Because a great deal of grain is used for animal food and humans consume huge quantities of cereal products as food, these poisonous dusts are not used in this country.

The combination of pyrethrins and piperonyl butoxide, known as "Pyrenone," is highly effective against the grain infesting insects was shown by Dove (1947) and Cotton et al. (1950). This combination has also been shown to be relatively non-toxic to warm blooded animals by Lehman (June, 1949). The toxicity of the pyrethrins appears to be so slight in warm blooded animals that no tissue damage has been reported. Piperonyl butoxide is relatively inactive pharmacologically according to Lehman (1949).

Sarles et al. (1949) reported that piperonyl butoxide would be expected to be only acutely toxic to warm blooded animals when ingested in extremely high amounts that would represent a very high dosage. From this data, it would seem impossible for conditions to be such that the necessary amount of the material needed to produce symptoms would be ingested during the normal use of this material as an insecticide.

The estimated fatal dose of pyrethrins to humans, based on studies of the major toxic action of insecticides, is 100 grams (Lehman, April 1949). Lehman (1948) also stated that the combination of pyrethrins and piperonyl butoxide appears to be the safest insecticidal material for use from all standpoints.

The pyrethrins are rapidly detoxified by hydrolysis in the alimentary canal and tissues of warm blooded animals. Chrysanthemum monocarboxylic acid is excreted in the urine. Brown (1951, p 485) stated that because of this action, the pyrethrins exhibit no chronic toxicity.

That the pyrethrins are effective in protecting grain against insect attack has been shown by Parkin (1951). Formulations of ground pyrethrum flowers and talc at strengths of 0.97 and 0.70 percent gave excellent control of the granary weevil in wheat when used at concentrations of 0.25 percent in grain of the 0.97 percent powder and 0.5 percent in grain of the 0.70 percent powder.

Small quantities of the insecticide were observed to cause a definite reduction in the emergence of the granary weevil. It is believed that this is caused by interference with oviposition. This is thought to occur either through irritation of the adults so that they cannot remain still long enough to complete the complex cycle of oviposition, or through interference with neuromuscular coordination.

Pyrethrum powders, both alone and diluted with diatomaceous earth, gave up to eight months protection to bagged wheat and corn exposed to natural infestation according to Beckley (1948). The combination of diatomaceous earth and pyrethrum was applied at the rate of two pounds per 200 pounds of grain and pyrethum alone was applied at the rate of one pound per 200 pounds of grain.

Tests by Goodwin-Bailey and Holborn (1952) showed that wheat treated with a dust containing 0.04 percent pyrethrins and 0.8 percent piperonyl butoxide at the rate of one pound per 300 pounds of wheat was protected for a period of 11 months. The granary weevil and the sawtoothed grain beetle were the test insects. The protection was equal over the 11 month storage period, but the sawtoothed grain beetle was less resistant to the dust than the granary weevil.

Watts and Berlin (1950) have shown that marked synergism between piperonyl butoxide and pyrethrins exists against the rice weevil. Four ratios of piperonyl butoxide to pyrethrins, 5:1, 10:1, 13.3:1, and 20:1 gave above 90 percent control or better over a period of 30 days. This work showed that the synergism operates over a wide range against this insect. The commercial formulation of Pyrenone Grain Protectant has piperonyl butoxide and pyrethrins in a ratio of 16:1, according to Dove (1952).

Field tests using the commercial formulation of Pyrenone Grain Protectant were reported by Dove (1951). He stated that 800 bushels of hybrid seed corn were treated in August, 1949 and the corn was in perfect condition after 21 months of storage.

Untreated corn was almost completely destroyed by the next spring.

Insect population build-up was slight in wheat treated with a dust containing 1.1 percent piperonyl butoxide and 0.08 percent pyrethrins applied at the rate of 75 pounds per 1000 bushels in farm bins according to White (1952).

Wilbur (1952) found that the moisture content of wheat treated with a dust containing 1.1 percent piperonyl butoxide and 0.08 percent pyrethrins had a definite effect on the effectiveness of the dust against the rice weevil and the sawtoothed grain beetle in laboratory tests. With an increase in moisture content, the effectiveness of the dust decreased. Field tests using this same dust on wheat at the rate of 75 pounds per 1000 bushels showed complete protection at moisture contents of between 13 and 15 percent. The field conditions provided an opportunity for the repellent action of the dust to act, whereas the laboratory tests did not.

The Test Insects

The interaction of temperature, relative humidity, and moisture content of the grain exerts a great deal of influence upon the rate of development and the degree of infestation of the rice weevil according to Reddy (1950). Oviposition occurs in grain with 9 percent moisture, but the eggs fail to hatch. A moisture content of 17.6 percent appears to be the most favorable for development of the rice weevil and a moisture content of 13.2 percent closely approaches the 17.6 percent level for favorability. Reddy (1950) stated that a temperature of 86 degrees Fahrenheit is the most favorable for the development of this insect.

Birch (1945) found that no oviposition of the rice weevil occurred in wheat with a moisture content of below 10 percent and little difference appeared at 11 and 12 percent moisture. He also observed that the average length of life was three months for the females and two months for the males in grain with satisfactory conditions for development. In another paper, Birch (1945) found that the egg stage of the rice weevil was the most resistant to dry conditions in wheat.

The rice weevil completes its development most rapidly at a temperature of 84.38 degrees Fahrenheit according to Birch (1945).

The ecology of the granary weevil closely parallels that of the rice weevil except that it is more resistant to cold temperature and little breeding occurs in grain of 10 and 11 percent moisture unless the temperature is 85 to 90 degrees Fahrenheit, according to Shedd and Cotton (1949). At temperatures of 86 degrees Fahrenheit and above, the granary weevil rapidly becomes sterile and breeding drops off (Blacklith, 1949). The rice weevil will continue breeding at this temperature over a long period of time.

Moisture contents of 11 to 17 percent are the most favorable for larval development of the sawtoothed grain beetle according to Schwardt (1934). The beetle is long lived and has been known to survive for three years. Back and Cotton (1926) found that the average life of the adults to be from six to ten months. The life cycle is passed in 23 to 32 days at a temperature of 80 degrees Fahrenheit.

The flat grain beetle develops faster at temperatures above 80 degrees Fahrenheit (Rilett, 1949). The insects live over a wide range of moisture contents and are relatively long lived. Apt (1950) kept the adults alive for four months with every indication of a much longer life.

MATERIALS AND METHODS

The Toxicant

The Pyrenone Grain Protectant used throughout the experiment was obtained from the U. S. Industrial Chemicals Company, holders of the trademark, "Pyrenone." (Fig. 1, Plate I) The protectant was packed in a 50 pound bag and consisted of the commercial formulation available for use by the public. The protectant was made up of the following ingredients:

	Percent
Pyrethrins	0.05
Technical Piperonyl Butoxide	0.80
Fibrous Talc	99.15

The diluent, according to Dr. W. E. Dove of the U. S. Industrial Chemicals Company, possessed the following properties and chemical constituents:

	Percent
Ignition loss	6.91
SiO_2	39.32
Al_2O_3	9.69
MgO	23.36
CaO	2.68
Fe_2O_3	0.648
MnO	0.102
$CaCO_3$	17.29
Color	White
Granulation	99 percent through a 325 mesh
Specific gravity	2.6
Quick wettability	

The Test Insects

The test insects consisted of four species that are among those most commonly found infesting stored grain throughout the United States. They included: Sitophilus oryza (L.), the rice weevil; Sitophilus granarius (L.), the granary weevil; Oryzaephilus surinamensis (L.), the sawtoothed grain beetle; and Laemopholoeus spp., the flat grain beetle. They were reared in the culture room of the stored products pests laboratory of the Department of Entomology.

The rice weevil and the granary weevil were reared separately in culture media of hard red winter wheat at a moisture content of 13.5 to 14.5 percent. The flat grain beetle and the sawtoothed grain beetle were reared separately in a culture media of rolled oats of an undetermined moisture content. The temperature in the culture room was maintained at 80 degrees Fahrenheit at all times and the relative humidity was approximately 70 percent.

The culture media was exposed to the adults of the respective test insects for a period of seven days. The adults were removed by screening and aspiration and the cultures replaced in the rearing room. In all cases, the rice and granary weevils were exposed to the treated grain when the adults were from one to three weeks old. The cultures of the flat grain beetle and the sawtoothed grain beetle were not reworked and no age determination was made. The rearing jars are illustrated in Fig. 2, Plate I.

The insects to be used in the tests were removed from the culture jars twenty-four hours prior to the beginning of the exposure period in the treated grain. This was done to condition the insects and to facilitate rapid infestation of the test grain following the application of the protectant.

Preparation of the Grain Prior to the Tests

The grain used in the experiment consisted of shelled, hybrid yellow corn and grain sorghum obtained from the Department of Agronomy at Kansas State College. The varieties of the corn and sorghum were unknown, but they were commercially grown varieties.

Both the corn and the sorghum were rough cleaned to remove the large pieces of foreign material and chaff. The greatest percentage of normal dust and cracked kernels were not removed so

EXPLANATION OF PLATE I

Fig. 1

The 50 pound bag of Pyrenone Grain Protectant from which the protectant was taken for use throughout the tests.

Fig. 2

Jars containing the cultures of the four test insects in the rearing room of the laboratory.

PLATE I

Fig. 1

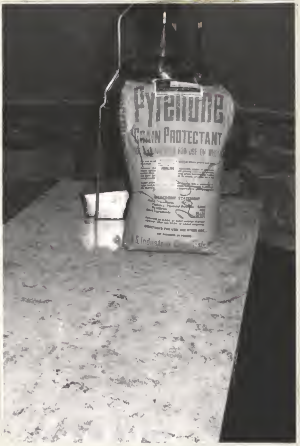


Fig. 2

as to have the samples resembling a commercially stored lot of grain. The corn and the sorghum contained a few sawtoothed grain beetles which were removed by the rough cleaning process. The method of cleaning the grain is shown in Fig. 1, Plate II.

To prevent further development of any insect that was not separated from the grain during cleaning, the corn and the sorghum were packed in new 25 pound cotton bags and placed in commercial cold storage at a temperature of zero degrees Fahrenheit for 12 days. Following the cold storage, the grain was removed from the bags and placed in steel drums with a clamp type lid and stored at room temperature in the laboratory.

Supplementary Equipment

The test jars used in the tests were one quart, wide-mouthed Mason fruit jars and had screw top lids with removable centers. New jars were used at the beginning of the tests and were thoroughly washed with soap and water before being used in following tests.

The grain was treated with the protectant by placing the grain in a one gallon wide-mouthed glass jar and adding the protectant to the grain as it was placed in the jar.

Other equipment used included a Steinlite moisture tester, a glass enclosed laboratory balance accurate to 1/100 of a gram, and a Boerner grain divider. The aspirator used to handle the insects was driven by an electric motor and white enamel pans were used for counting the insects before and after exposure to the treated grain.

Conditions of the First Series of Tests

The first phase of the experiment was a test to determine the effectiveness of the Pyrenone Grain Protectant against the test insects in shelled corn and sorghum of five different moisture levels. The grain was adjusted to moisture contents of 11, 12, 13, 14, and 15 percent. The protectant was applied to each of the grains at ten different rates of application. The applications were made at the rate of 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 pounds of protectant per 1000 bushels of grain. The recommended rate of application is 100 pounds per 1000 bushels.

The exposure period was 21 days which was carried out at a temperature of 80 degrees Fahrenheit in the rearing room of the laboratory.

Adjustment of the Moisture Content of the Grain

Moisture adjustment of the grain was carried out prior to the treatment with the protectant. A sufficient amount of grain was weighed out for each moisture level and held separately in the steel drums. The separate lots of grain were kept at room temperature for seven days. Following the storage period, each lot was tested for moisture content using the Steinlite moisture tester. Each lot was sampled five times and the moisture content determined on each sample. The average of the five moisture readings was taken and used as the moisture content of the entire lot. An illustration of the determination of the moisture content is shown in Fig. 2, Plate II.

As each lot of grain was tested for moisture content, it was examined for infestation. No insects were found in any lot of grain and these were designated as non-infested. This indicated that the original screening process and the storage of the grain in the cold room had effectively removed or destroyed the small infestation that had been present in the corn and sorghum at the time it was obtained.

Using the moisture content figure as a basis, each lot of grain was adjusted to the desired moisture level by adding distilled water or drying the grain.

The moisture content adjusted by the addition of water was carried out following a method outlined by Cotton[1] and cited by Rowell (1950).

The lots of grain were placed in the steel drums with the lids that made it possible to seal the drums practically airtight. The necessary amount of distilled water was poured over the grain surface. The proper amount of water needed to adjust

[1]Senior Entomologist, U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, Manhattan, Kansas.

EXPLANATION OF PLATE II

Fig. 1

The author using the large cleaning screens to rough clean the corn and sorghum prior to the adjustment of the moisture content.

Fig. 2

The author determining the moisture content of the grain showing the equipment used in making the determination.

PLATE II

Fig. 1

Fig. 2

the moisture content was calculated in the following manner:

Amount of grain to be adjusted in moisture content	50,000 grams
Moisture content of the grain	10 percent
Final moisture content desired	11 percent

Procedure: 100 minus 10 gives 90
100 minus 11 gives 89

90 divided by 89 gives 1.01123

The first digit, which will always be 1, is dropped. The remainder of the quotient is used as the multiple factor. Thus, 50,000 grams times 0.01123 gives 561.5, or the number of milliliters of water necessary to raise the moisture content to the desired level.

After the necessary amount of water had been calculated and added to the grain (Fig. 1, Plate III), the lid was clamped on the drum and it was rolled over and over on the floor of the laboratory. This method of mixing the grain was repeated several times each day for six days. Following this period of mixing, the moisture content was again taken to check the results of the moisture adjustment.

Lots of grain that needed drying to adjust the moisture content were spread on a large table in a thin layer. An electric fan was placed at one end of the table and air was blown across the layer of grain. This procedure is illustrated in Fig. 2, Plate III. The moisture content was checked periodically until the entire lot of grain had reached the desired level. Approximately ten hours of drying was needed to reduce the moisture content one percent. When the grain had been adjusted to the

EXPLANATION OF PLATE III

Fig. 1

The author adding the calculated amount of distilled water to the grain in the steel drums to adjust the moisture content to the desired level.

Fig. 2

Shelled corn spread on the table in front of a fan to remove moisture and reduce the moisture to the desired level.

PLATE III

Fig. 1

Fig. 2

final moisture content it was stored in the steel drums with the lids sealed.

In all cases, the moisture content did not vary over 0.3 percent from the desired level at the time of treatment and infestation.

Treatment of the Grain with the Protectant

The entire series of tests with corn was treated and infested at one time and the series using sorghum was treated and infested following the corn series. Each moisture level was handled separately from the others and each lot was treated with the various dosage levels of protectant before treatment began on the succeeding lots.

The corn was weighed out in 1000 gram portions and the sorghum was weighed out in 2000 gram portions on a laboratory balance. The protectant was weighed according to the calculated amount. A simple conversion from pounds per 1000 bushels to grams per 1000 grams was made for each dosage level. The weighed amounts of grain and protectant were introduced into the one gallon mixing jar. This was done by pouring approximately one-fourth of the grain into the jar and adding approximately one-fourth of the protectant on top of the grain. By adding the grain in fractions followed by a fraction of the protectant, partial distribution was obtained before mixing was started. The mixing jar was filled approximately three-fourths full so as to leave space in the top of the jar to allow the grain to move about freely during the mixing.

When the grain and protectant had been added to the mixing jar, the lid was screwed down tightly and the jar rotated to thoroughly distribute the protectant throughout the grain. The mixing was done by holding the jar by the top and the bottom with the hands and alternately raising one end and then the other. At the same time, the jar was rotated forward and backward through an angle of approximately 180 degrees. This cycle was repeated 100 times for each treatment. The end effect was to subject the grain to a tumbling action and inspection showed that this method thoroughly coated each kernel with the protectant. The method of mixing the grain and the protectant is illustrated in Fig. 1, Plate IV.

After the treatment, the grain was placed in the one quart fruit jars. In the case of the corn, each 1000 gram lot was divided and placed in two jars. The 2000 gram lots of sorghum were divided and placed in four jars. This was done by bringing the level of the grain in the jars to the same level. By this means, each test container held approximately 500 grams of grain. The grain was not weighed into the jars because the extra steps necessary would have caused a loss of the protectant during the transfer operation.

Infestation of the Treated Grain with the Test Insects

Each of the ten dosage levels in each of the five moisture levels of the corn and sorghum were replicated four times. Two of the replicate jars for each dosage level were placed in one group and the remaining two replicate jars were placed in another group. Two test jars containing 500 grams of grain each were left untreated as controls for each group. Each dosage level had two jars of treated grain and two jars of untreated grain as a control. The grain for the control sample was taken from the moisture adjusted lots just prior to treatment with the protectant.

Each test jar in the first group was infested with 50 adult rice weevils and 50 adult sawtoothed grain beetles. Each jar in the second group was infested with 50 adult granary weevils and 50 adult flat grain beetles. The test insects had previously been screened from the culture jars and held for twenty-four hours without food. The insects were introduced into the flat enamel pan and picked up with the aspirator as shown in Fig. 2, Plate IV.

After each test jar had been infested, the lid was put on by inverting the center section so as to have the rubber sealing ring away from the rim of the jar. This made it possible to seal in the moisture and not have the jar sealed completely air tight. This method proved to be successful in retaining the desired moisture content in the grain throughout the exposure period.

The test jars were placed in the rearing room and held for a period of 21 days as shown in Fig. 1, Plate V.

EXPLANATION OF PLATE IV

Fig. 1

The author treating the grain with the protectant by tumbling the grain and protectant in a wide-mouthed one gallon glass jar. The balance used to weigh out the protectant is shown on the table.

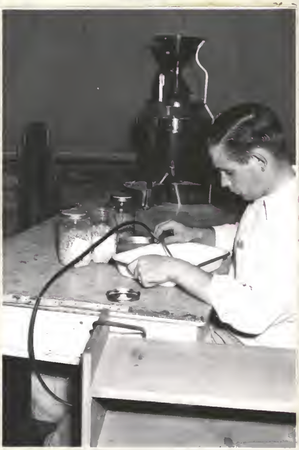
Fig. 2

The author using the aspirator to pick up the test insects from the enamel pan for introduction into the test jars.

PLATE IV

Fig. 1

Fig. 2



Examination of the Grain Following the Exposure Period

When the exposure period of 21 days had elapsed, the test jars were removed from the rearing room for examination. The grain in each jar was screened to remove the insects and the grain was replaced in the jar for further observation.

The adult insects, screened from the grain, were picked up with the aspirator and placed in a white enamel pan for examination. This examination is illustrated in Fig. 2, Plate V.

Following the removal of the adult insects from the screenings, the screenings were replaced in the jar along with the grain so any immature forms of the flat grain beetle or saw-toothed grain beetle would have an opportunity to develop. The test jars were then replaced in the rearing room for a period of 31 days to determine the extent of reproduction that had occurred during the original exposure period.

The adults screened from the test jars were examined and any insect showing any movement was counted as alive. The numbers of dead and alive insects were determined and recorded and the sums taken to check the recovery of the original insects placed in the jars. In all cases, the number of adult insects removed from the grain corresponded to the number introduced at the beginning of the exposure period.

Examination of the Jars to Determine the Extent of Reproduction

The test jars were re-examined for the presence of insects

EXPLANATION OF PLATE V

Fig. 1

The treated jars of grain in the laboratory rearing room during the exposure period.

Fig. 2

The author using the aspirator and magnifying light to determine the mortality of the test insects following the period of exposure.

PLATE V

Fig. 1

Fig. 2

following the additional storage of 31 days. The number of live insects of each species was counted until the number reached 50 and recorded. Immature stages of the flat grain beetle and the sawtoothed grain beetle were noted, if present, and recorded.

The two replicate jars of the dosage levels of 25, 50, 75, 100, 150, 200, and 250 pounds per 1000 bushels of the 15 percent moisture sorghum were mixed together. A 1000 gram sample of the non-infested sorghum used at the beginning of the experiment and 1000 grams of untreated control sorghum at 15 percent moisture were set aside. These lots of sorghum were passed through a Boerner divider until the sample was broken down into approximately 10 gram lots. The kernels from this small sample were arranged on a plate and photographed with X-ray to determine the extent of the internal infestation of the rice and granary weevil.

The same procedure was followed using the shelled corn except that the dosage levels of 75 and 100 pounds per 1000 bushels were used. These small samples were mounted on a plate and photographed with X-ray along with the sorghum.

The number of kernels in each sample were not the same and no numerical conclusions were intended. The radiographs were made to illustrate the effects of the protectant on reproduction of the two weevils.

Tests to Determine the Effect of Storage on the Protectant

This part of the experiment was carried out to determine the effectiveness of the protectant after storage for various lengths of time at different temperatures on shelled corn of two different moisture levels.

This phase of the experiment was carried out by treating shelled yellow corn with moisture contents of 11 and 14 percent with the protectant at a rate of 75 pounds per 1000 bushels. The treated, non-infested lots of grain were then stored for a period of two, four, and six months at temperatures of 45 and 80 degrees Fahrenheit. Following this period of storage, the corn was infested with the test insects and held for a period of 21 days at 80 degrees Fahrenheit.

This part of the experiment was carried out in exactly the same way as the previous part. The only exception was the period of storage before infestation. The same methods of examination were followed after the exposure period except that no X-ray photographs were taken of the corn used in this part of the experiment.

EXPERIMENTAL RESULTS

The Effectiveness of Pyrenone Grain Protectant Against the Rice Weevil

Shelled Corn. The treatment of shelled corn to control the rice weevil was completely successful at all dosage levels used with the exception of 25 pounds per 1000 bushels. The control of this insect was 100 percent in all dosage levels from 50 to 250 pounds per 1000 bushels.

The moisture content of the grain did not affect the mortality of the rice weevil where the dosage was 50 pounds per 1000 bushels or higher. The moisture content did have some effect on the mortality at a dosage of 25 pounds per 1000 bushels. Mortality increased somewhat as the moisture content decreased. At a moisture level of 11 percent, the highest mortality was obtained, 89 percent, and this decreased progressively until a mortality of 77 percent was obtained at a moisture content of 15 percent.

Control samples showed the effect of various moisture contents on the rice weevil. A range of mortality of the adult insects from 0 to 4 percent was obtained in the corn with 15 percent moisture. The average mortality was 1.7 percent. The mortality steadily increased until the maximum was reached in the corn of 11 percent moisture. A range of 10 to 16 percent mortality occurred, with the average being 12.6 percent. The mortalities of the rice weevil in the corn tests are shown in Tables 1 through 5.

Sorghum. The treatment of sorghum with the protectant gave variable results against the rice weevil. The moisture content of the sorghum had a definite effect on the mortality. As the moisture content increased in the sorghum from 11 to 15 percent, the mortality of the rice weevil steadily decreased.

A mortality of 100 percent was obtained in the 11 percent sorghum at dosages of 50 pounds per 1000 bushels and above. These dosages gave mortalities of 90 percent or above in the sorghum of 12 percent moisture while a dosage of 100 pounds per 1000 bushels or higher was needed to give mortalities above 90 percent in the sorghum with a moisture content of 13 percent. The highest dosage of 250 pounds per 1000 bushels was the only one giving 90 percent mortality in 14 percent moisture sorghum. The sorghum at 15 percent moisture had a high mortality of 86 percent at a dosage of 250 pounds per 1000 bushels.

The decrease of mortality with the increase in moisture content followed the same general pattern throughout the five levels of moisture. In all cases, the mortalities of the rice weevil were higher in each dosage category as the moisture levels decreased from 15 to 11 percent.

The highest mortality in the control jars occurred in the 11 percent sorghum. A range of 12 to 34 percent occurred with the average being 22.4 percent. The lowest mortality occurred in the 15 percent moisture sorghum. A range of 0 to 3 percent mortality occurred and the average mortality was 1.5 percent.

The mortalities of the rice weevil in the sorghum tests are shown in Tables 1 through 5.

The Effectiveness of Pyrenone Grain Protectant Against the Granary Weevil

Shelled Corn. Complete control of the granary weevil was obtained in shelled corn at all moisture levels with dosages of 75 pounds per 1000 bushels and above. Mortality above 90 percent was obtained with 50 pounds per 1000 bushels in 11 and 12 percent moisture corn. The lowest dosage of 25 pounds per 1000 bushels gave a high mortality of 73 percent and the mortality decreased to a low of 48 percent as the moisture content increased to 15 percent. The mortality in the dosage categories below 75 pounds per 1000 bushels fell steadily as the moisture content increased.

The mortality of the granary weevil in the 10 control jars decreased as the moisture content increased. The 11 percent corn controls had a mortality range of 8 to 13 percent with an average mortality of 10.5 percent. The control jars with 15 percent moisture corn had a mortality range of 0 to 3 percent with an average of 1.5 percent.

The mortalities of the granary weevil in the treated and untreated corn are shown in Tables 1 through 5.

Sorghum. The mortality of the granary weevil decreased steadily with an increase in moisture content. The moisture content exhibited a definite effect on the effectiveness of the protectant.

The highest levels of mortality were obtained in the 11 percent moisture sorghum. Dosages from 125 to 250 pounds per 1000 bushels gave mortalities above 90 percent. A high of 98 percent mortality occurred at dosages of 150 to 250 pounds per 1000 bushels.

Dosage levels of 100 pounds per 1000 bushels and below failed to give 90 percent mortality in all cases.

As the moisture content of the sorghum increased above 11 percent, the dosage necessary to obtain 90 percent mortality or above increased. A dosage of 150 pounds per 1000 bushels was necessary to obtain a mortality of 90 percent or above in 12 percent moisture sorghum and 200 pounds per 1000 bushels was needed at 13 percent moisture. No mortalities of 90 percent or above were obtained with any dosage level used in sorghum of 14 and 15 percent moisture.

The mortality of the granary weevil in the treated sorghum was higher in each dosage level in every instance as the moisture content decreased from 15 to 11 percent moisture.

The untreated control sorghum showed a decreasing mortality with increasing moisture content. The 11 percent moisture sorghum had a mortality range of 6 to 14 percent with an average mortality of 9.18 percent. The 15 percent moisture controls had a mortality range of 0 to 2 percent and an average of 1.2 percent.

The mortalities of the granary weevil in the treated and untreated sorghum tests are shown in Tables 1 through 5.

The Effectiveness of Pyrenone Grain Protectant Against the Flat Grain Beetle

Shelled Corn. The protectant was completely effective against the flat grain beetle at all dosage levels and all moisture levels except at the lowest dosage used. The dosage of 25 pounds per 1000 bushels gave mortalities lower than 90 percent in all the moisture levels. The mortality decreased as the moisture content increased. A high of 89 percent mortality was obtained at the 11 percent moisture level and the lowest mortality of 74 percent occurred in the 15 percent moisture corn.

The mortality in the untreated control corn decreased as the moisture content increased. A mortality range of 6 to 11 percent occurred with an average of 8.8 percent in 11 percent corn. Control jars of corn with 15 percent moisture had a mortality range of 1 to 3 percent with an average of 1.8 percent.

The mortalities of the flat grain beetle in corn in both the treated and untreated jars are shown in Tables 1 through 5.

Sorghum. The results of the tests against the flat grain beetle in sorghum were quite variable at dosage levels below 100 pounds per 1000 bushels. At this dosage and above, 100 percent control was obtained.

The sorghum with 11 and 12 percent moisture showed mortalities above 90 percent for all dosage levels below 100 pounds per 1000 bushels. The sorghum with 13 percent moisture showed mortalities below 90 percent with dosages of 25 and 50 pounds per 1000 bushels and a mortality of above 90 percent at 75 pounds per

1000 bushels. Sorghum with 14 and 15 percent moisture required a dosage of 100 pounds per 1000 bushels to obtain mortalities above 90 percent. At this dosage, 100 percent control resulted.

The mortalities obtained at dosages below 100 pounds per 1000 bushels were successively lower in all cases as the moisture content increased.

The mortalities in the control jars decreased as the moisture content in the sorghum increased. The control jars of 11 percent moisture sorghum had a mortality range of 8 to 14 percent and an average mortality of 10.8 percent. The 15 percent moisture sorghum had a mortality range of 1 to 2 percent and an average of 1.2 percent.

The results of the tests against the flat grain beetle in sorghum are shown in Tables 1 through 5.

The Effectiveness of Pyrenone Grain Protectant Against the Sawtoothed Grain Beetle

Shelled Corn. Dosages of 50 pounds per 1000 bushels and above gave 100 percent mortality of this insect at all moisture levels. The dosage level of 25 pounds per 1000 bushels gave a mortality of 54 percent in 11 percent moisture corn and 19 percent mortality at the 15 percent moisture level. The mortalities decreased successively in all cases as the moisture content increased in the 25 pounds per 1000 bushels dosage category.

The mortalities in the control jars decreased as the moisture content increased. The mortality range in the control jars of 11 percent corn was 7 to 12 percent with an average of 9.5 percent. The control jars of 15 percent moisture corn had a mortality range of 0 to 3 percent with an average of 1.6 percent.

The results of this series of tests are shown in Tables 1 through 5.

Sorghum. The dosage of 100 pounds per 1000 bushels and above gave 100 percent mortality at all moisture levels. The dosage of 25 pounds per 1000 bushels gave mortalities that fell in the range of 4 to 11 percent. The mortality range increased at a dosage of 50 pounds per 1000 bushels with a high of 97 percent at 11 percent moisture and a low of 30 percent at 15 percent moisture. The dosage of 75 pounds per 1000 bushels gave a small mortality range of 80 to 100 percent. The 11 percent moisture sorghum had a mortality of 100 percent and the sorghum at 15 percent had a mortality of 80 percent.

The control samples showed a decrease in mortality as the moisture content of the sorghum increased. The control jars with 11 percent moisture sorghum had a mortality range of 3 to 12 percent and an average mortality of 6.2 percent. The 15 percent moisture control jars had a mortality range of 0 to 3 percent and an average mortality of 1.3 percent.

The mortalities of the sawtoothed grain beetle in this series of tests are shown in Tables 1 through 5.

Table 1. Results of tests to determine the effectiveness of Pyrenone Grain Protectant applied to shelled corn and sorghum at 11 percent moisture showing the mortalities as percent of the rice weevil, the granary weevil, the flat grain beetle, and the sawtoothed grain beetle dead in the two replicate jars of treated and untreated grain for each dosage level of protectant.

Insect	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
Rice weevil	89	100	100	100	100	100	100	100	100	100
Control	16	13	11	10	13	14	13	11	12	13
Granary weevil	73	95	100	100	100	100	100	100	100	100
Control	12	10	11	9	13	8	10	11	10	11
Flat grain beetle	89	100	100	100	100	100	100	100	100	100
Control	10	8	11	8	10	9	10	7	6	9
Sawtoothed grain beetle	54	100	100	100	100	100	100	100	100	100
Control	7	10	9	11	7	10	11	9	12	9
					Sorghum					
Rice weevil	94	100	100	100	100	100	100	100	100	100
Control	24	34	12	22	26	22	24	22	22	20
Granary weevil	18	56	79	89	97	98	98	98	98	98
Control	14	10	10	8	12	6	8	10	11	9
Flat grain beetle	98	99	98	100	100	100	100	100	100	100
Control	12	8	8	8	14	13	14	9	10	12
Sawtoothed grain beetle	11	97	100	100	100	100	100	100	100	100
Control	7	6	12	6	4	3	6	5	7	6

Table 2. Results of tests to determine the effectiveness of Pyrenone Grain Protectant applied to shelled corn and sorghum at 12 percent moisture showing the mortalities as percent of the rice weevil, the granary weevil, the flat grain beetle, and the sawtoothed grain beetle dead in the two replicate jars of treated and untreated grain for each dosage level of protectant.

Insect	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
Rice weevil	87	100	100	100	100	100	100	100	100	100
Control	11	10	10	11	12	10	12	13	9	11
Granary weevil	64	91	100	100	100	100	100	100	100	100
Control	8	7	8	11	11	10	9	8	9	9
Flat grain beetle	87	100	100	100	100	100	100	100	100	100
Control	8	6	6	3	4	5	5	4	6	4
Sawtoothed grain beetle	40	100	100	100	100	100	100	100	100	100
Control	5	6	4	7	8	7	3	8	5	4
						Sorghum				
Rice weevil	86	90	96	96	97	98	99	98	98	98
Control	9	7	7	8	8	10	8	8	9	8
Granary weevil	16	47	72	83	87	90	92	95	95	95
Control	8	7	9	8	10	7	7	10	8	8
Flat grain beetle	95	96	98	100	100	100	100	100	100	100
Control	2	3	2	0	2	1	3	2	2	3
Sawtoothed grain beetle	10	60	98	100	100	100	100	100	100	100
Control	2	1	0	3	4	3	2	2	1	0

Table 3. Results of tests to determine the effectiveness of Pyrenone Grain Protectant applied to shelled corn and sorghum at 13 percent moisture showing the mortalities as percent of the rice weevil, the granary weevil, the flat grain beetle, and the sawtoothed grain beetle dead in the two replicate jars of treated and untreated grain for each dosage level of protectant.

Insect	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
Rice weevil	85	100	100	100	100	100	100	100	100	100
Control	6	6	8	7	6	7	8	7	7	6
Granary weevil	59	88	100	100	100	100	100	100	100	100
Control	7	7	8	7	6	6	6	7	5	6
Flat grain beetle	83	100	100	100	100	100	100	100	100	100
Control	7	6	6	5	6	4	6	5	4	4
Sawtoothed grain beetle	34	100	100	100	100	100	100	100	100	100
Control	6	5	6	4	4	5	6	6	5	4
					Sorghum					
Rice weevil	56	69	77	90	92	93	97	97	98	98
Control	7	5	5	7	6	5	7	6	5	4
Granary weevil	10	20	40	70	75	84	86	90	92	92
Control	6	5	4	7	6	5	4	5	6	6
Flat grain beetle	67	80	96	100	100	100	100	100	100	100
Control	1	1	0	0	1	0	1	2	0	0
Sawtoothed grain beetle	6	40	90	100	100	100	100	100	100	100
Control	1	0	1	1	2	1	2	2	1	0

Table 4. Results of tests to determine the effectiveness of Pyrenone Grain Protectant applied to shelled corn and sorghum at 14 percent moisture showing the mortalities as percent of the rice weevil, the granary weevil, the flat grain beetle, and the sawtoothed grain beetle in the two replicate jars of treated and untreated grain for each dosage level of the protectant.

Insect	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
	Shelled corn									
Rice weevil	84	100	100	100	100	100	100	100	100	100
Control	4	3	3	2	3	3	4	2	3	4
Granary weevil	54	86	100	100	100	100	100	100	100	100
Control	4	3	3	2	3	4	3	2	2	1
Flat grain beetle	79	100	100	100	100	100	100	100	100	100
Control	3	2	2	3	2	1	3	2	2	3
Sawtoothed grain beetle	25	100	100	100	100	100	100	100	100	100
Control	3	2	2	3	2	2	3	3	2	1
	Sorghum									
Rice weevil	5	25	39	61	67	72	76	83	88	90
Control	2	4	1	3	2	0	1	0	3	2
Granary weevil	1	6	6	26	63	68	71	76	84	86
Control	2	1	3	1	2	2	2	1	2	1
Flat grain beetle	4	29	88	100	100	100	100	100	100	100
Control	2	3	2	2	1	3	0	2	1	2
Sawtoothed grain beetle	6	33	87	100	100	100	100	100	100	100
Control	2	1	3	1	1	2	0	3	1	2

Table 5. Results of tests to determine the effectiveness of Pyrenone Grain Protectant applied to shelled corn and sorghum at 15 per cent moisture showing the mortalities as percent of the rice weevil, the granary weevil, the flat grain beetle, and the sawtoothed grain beetle in the two replicate jars of treated and untreated grain for each dosage level of the protectant.

Insect	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
Rice weevil	77	100	100	100	100	100	100	100	100	100
Control	1	4	2	1	3	2	1	2	1	0
Granary weevil	48	60	100	100	100	100	100	100	100	100
Control	2	3	1	0	1	2	3	1	1	1
Flat grain beetle	74	100	100	100	100	100	100	100	100	100
Control	2	2	3	1	2	2	1	1	2	2
Sawtoothed grain beetle	19	100	100	100	100	100	100	100	100	100
Control	3	2	2	1	2	0	1	2	1	2
					Sorghum					
Rice weevil	2	10	30	56	64	70	73	80	83	86
Control	2	1	1	2	0	1	3	2	2	1
Granary weevil	1	3	4	21	56	60	64	70	77	80
Control	2	2	1	0	2	2	1	1	2	0
Flat grain beetle	11	25	76	100	100	100	100	100	100	100
Control	1	2	1	0	1	2	2	1	2	0
Sawtoothed grain beetle	4	30	80	100	100	100	100	100	100	100
Control	2	1	1	1	2	3	0	1	1	1

Reproduction of the Test Insects in the Grain

The reproduction of the four test insects in the corn and sorghum is shown in Tables 6 through 9. None of the four insects reproduced in either grain when the mortality in the treated grain reached 90 percent or above. As the mortality in the treated grain decreased, the reproduction of all species increased.

Reproduction of all insects occurred in all control jars. The reproduction increased as the moisture content increased in the treated jars as well as in the control jars. The highest rate of reproduction occurred in both grains with the moisture content at 14 and 15 percent.

The reproduction of the rice and granary weevil is illustrated in Plates VI through XV. Samples of corn and sorghum at 15 percent moisture infested with the rice and granary weevils were subjected to X-ray to illustrate the amount of internal infestation present. Samples of the uninfested grain, control grain, and treated grain at different dosages were radiographed. The uninfested grain showed no internal infestation of either insect. The control grain showed a considerable amount of infestation. As the dosage was increased, the amount of internal infestation decreased. The corn showed a small amount of damage by the Angoumois grain moth, Sitotroga cerealella (Oliv.), which occurred before the grain was processed for the tests.

The radiographs show very little internal infestation in the samples in which the protectant gave a high mortality of the insects. The corn showed considerably less internal infestation than did the sorghum. The infestation of both insects still persisted in sorghum that had been treated with the protectant at the rate of 250 pounds per 1000 bushels.

Radiographs of the rice weevil in sorghum are shown in Plates VI through VIII and those of the rice weevil in corn in Plates IX and X. The radiographs of the granary weevil in sorghum are shown on Plates XI through XIII and the granary weevil infestation of corn is shown on Plates XIV and XV.

Table 6. Number of live adult rice weevils present in the two replicate jars of shelled corn and sorghum treated with the 10 dosage levels of the protectant following the 31 day storage period after the removal of the test insects from the treated grain.

Moisture content (percent)	Dosage in pounds per 100 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
11	3	n	n	n	n	n	n	n	n	n
12	5	n	n	n	n	n	n	n	n	n
13	8	n	n	n	n	n	n	n	n	n
14	10	n	n	n	n	n	n	n	n	n
15	14	n	n	n	n	n	n	n	n	n
					Sorghum					
11	n	n	n	n	n	n	n	n	n	n
12	3	n	n	n	n	n	n	n	n	n
13	19	10	7	n	n	n	n	n	n	n
14	af	af	af	24	20	19	10	7	3	n
15	af	af	af	35	29	23	15	5	1	3

n - No reproduction
af - Above fifty insects found

Table 7. Number of live adult granary weevils present in the two replicate jars of shelled corn and sorghum treated with the 10 dosage levels of the protectant following the 31 day storage period after the removal of the test insects from the treated grain.

Moisture content (percent)	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
11	7	n	n	n	n	n	n	n	n	n
12	11	n	n	n	n	n	n	n	n	n
13	13	2	n	n	n	n	n	n	n	n
14	18	4	n	n	n	n	n	n	n	n
15	23	14	n	n	n	n	n	n	n	n
					Sorghum					
11	af	33	12	2	n	n	n	n	n	n
12	af	39	22	12	8	n	n	n	n	n
13	af	af	36	19	12	8	5	n	n	n
14	af	af	af	31	19	13	10	7	6	4
15	af	af	af	42	24	20	17	15	12	8

n - No reproduction
af - Above fifty insects found

Table 8. Number of live flat grain beetles, both mature and immature, present in the two replicate jars of shelled corn and sorghum treated with the 10 dosage levels of the protectant following the 31 day storage period after the removal of the test insects from the treated grain.

Moisture content (percent)	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
	Shelled corn									
11	1	n	n	n	n	n	n	n	n	n
12	4	n	n	n	n	n	n	n	n	n
13	8	n	n	n	n	n	n	n	n	n
14	10	n	n	n	n	n	n	n	n	n
15	13	n	n	n	n	n	n	n	n	n
	Sorghum									
11	n	n	n	n	n	n	n	n	n	n
12	n	n	n	n	n	n	n	n	n	n
13	5	2	n	n	n	n	n	n	n	n
14	af	39	3	n	n	n	n	n	n	n
15	af	46	9	n	n	n	n	n	n	n

n - No reproduction
af - Above fifty insects found

Table 9. Number of live sawtoothed grain beetles, both mature and immature, present in the two replicate jars of shelled corn and sorghum treated with the 10 dosage levels of the protectant following the 31 day storage period after the removal of the test insects from the treated grain.

Moisture content (percent)	Dosage in pounds per 1000 bushels									
	25	50	75	100	125	150	175	200	225	250
					Shelled corn					
11	10	n	n	n	n	n	n	n	n	n
12	16	n	n	n	n	n	n	n	n	n
13	21	n	n	n	n	n	n	n	n	n
14	27	n	n	n	n	n	n	n	n	n
15	33	n	n	n	n	n	n	n	n	n
					Sorghum					
11	af	n	n	n	n	n	n	n	n	n
12	af	35	n	n	n	n	n	n	n	n
13	af	32	n	n	n	n	n	n	n	n
14	af	43	9	n	n	n	n	n	n	n
15	af	49	13	n	n	n	n	n	n	n

n - No reproduction
af - Above fifty insects found

EXPLANATION OF PLATE VI

Fig. 1

Radiograph of insect free sorghum prior to infestation with the rice weevil.

Fig. 2

Radiograph of sorghum from the control jars with a moisture content of 15 percent infested with the rice weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 25 pounds of the protectant per 1000 bushels infested with the rice weevil.

PLATE VI

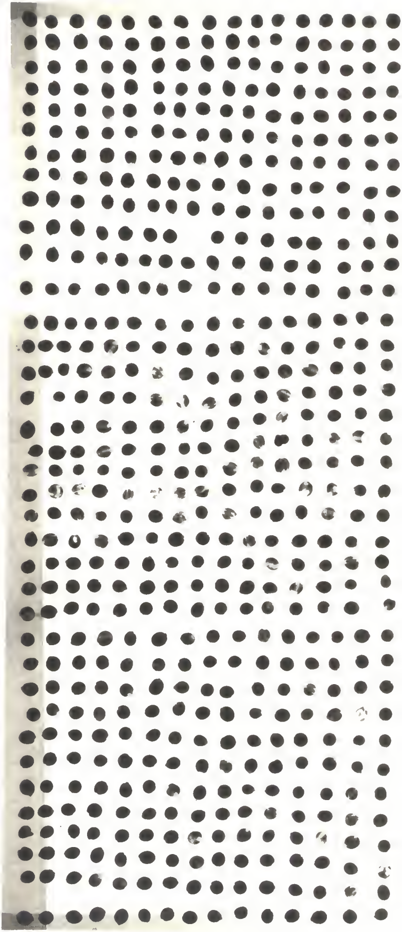


Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE VII

Fig. 1

Radiograph of sorghum from the test jars at 15 percent moisture treated with 50 pounds of the protectant per 1000 bushels infested with the rice weevil.

Fig. 2

Radiograph of sorghum from the test jars at 15 percent moisture treated with 75 pounds of the protectant per 1000 bushels infested with the rice weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 100 pounds of the protectant per 1000 bushels infested with the rice weevil.

PLATE VII

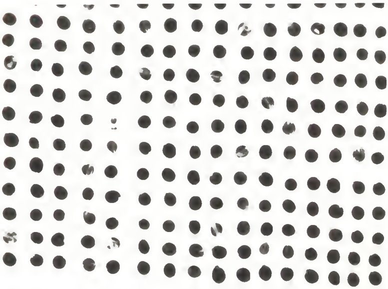


Fig. 1

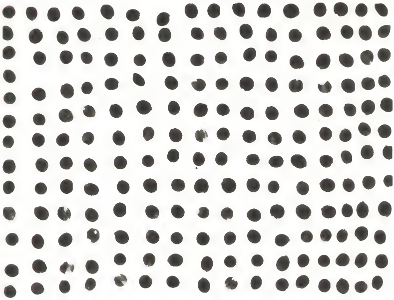


Fig. 2

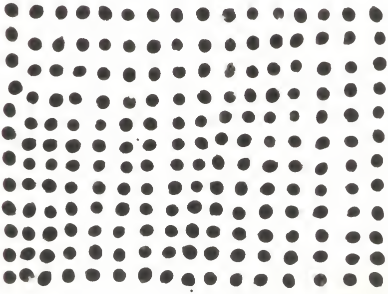


Fig. 3

EXPLANATION OF PLATE VIII

Fig. 1

Radiograph of sorghum from the test jars at 15 percent moisture treated with 150 pounds of the protectant per 1000 bushels infested with the rice weevil.

Fig. 2

Radiograph of sorghum from the test jars at 15 percent moisture treated with 200 pounds of the protectant per 1000 bushels infested with the rice weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 250 pounds of the protectant per 1000 bushels infested with the rice weevil.

PLATE VIII

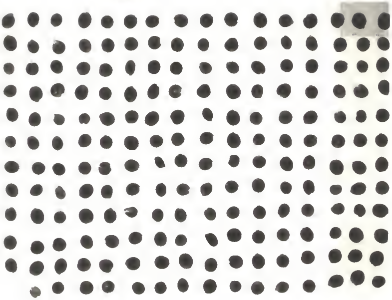


Fig. 1

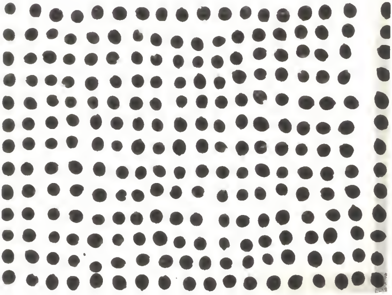


Fig. 2

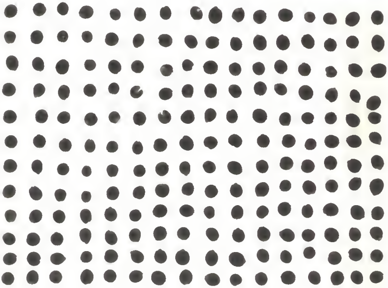


Fig. 3

EXPLANATION OF PLATE IX

Fig. 1

Radiograph of insect free corn prior to infestation with the rice weevil showing a few kernels which had been attacked by the Angoumois grain moth.

Fig. 2

Radiograph of corn from the control jars with a moisture content of 15 percent severely infested with the rice weevil.

PLATE IX

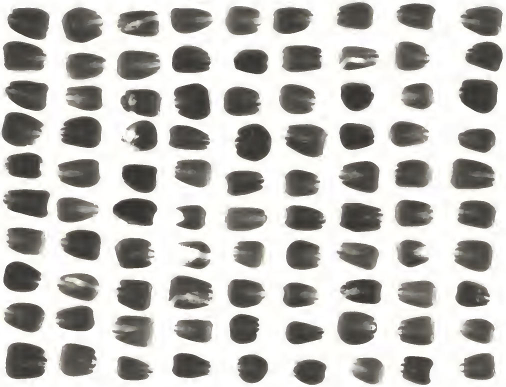


Fig. 1

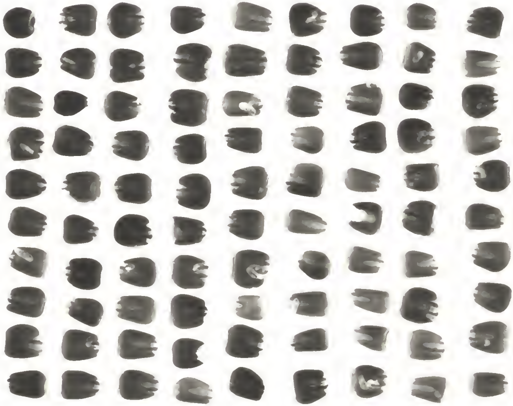


Fig. 2

EXPLANATION OF PLATE X

Fig. 1

Radiograph of corn from the test jars at 15 percent moisture treated with 75 pounds of the protectant per 1000 bushels infested with the rice weevil showing no internal infestation.

Fig. 2

Radiograph of corn from the test jars at 15 percent moisture treated with 100 pounds of the protectant per 1000 bushels infested with the rice weevil showing no internal infestation.

PLATE X

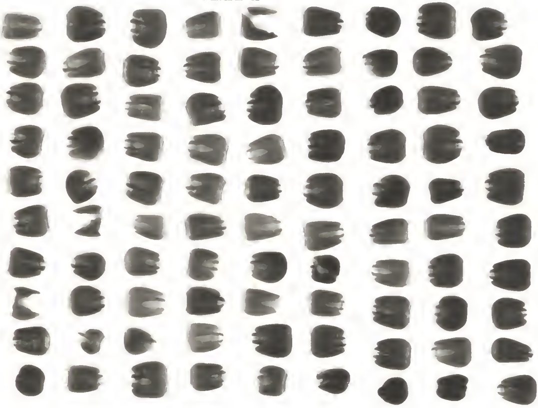


Fig. 1

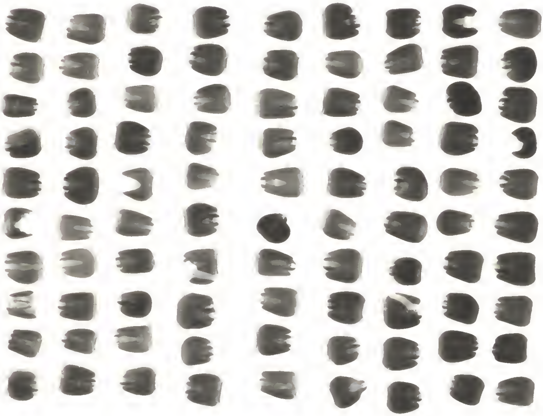


Fig. 2

EXPLANATION OF PLATE XI

Fig. 1

Radiograph of insect-free sorghum prior to infestation with the granary weevil.

Fig. 2

Radiograph of sorghum from the control jars with a moisture content of 15 percent infested with the granary weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 25 pounds of the protectant per 1000 bushels infested with the granary weevil.

PLATE XI

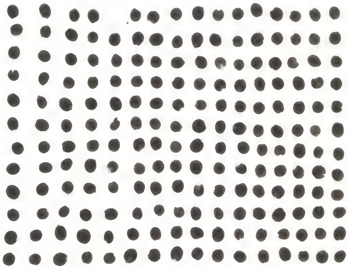


Fig. 1

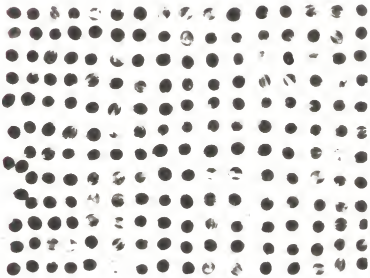


Fig. 2

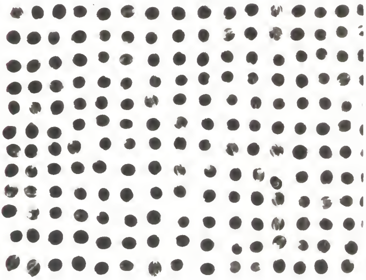


Fig. 3

EXPLANATION OF PLATE XII

Fig. 1

Radiograph of sorghum from the test jars at 15 percent moisture treated with 50 pounds of the protectant per 1000 bushels infested with the granary weevil.

Fig. 2

Radiograph of sorghum from the test jars at 15 percent moisture treated with 75 pounds of the protectant per 1000 bushels infested with the granary weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 100 pounds of the protectant per 1000 bushels infested with the granary weevil.

PLATE XII

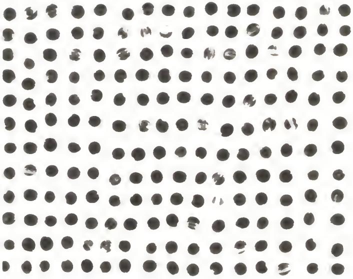


Fig. 1

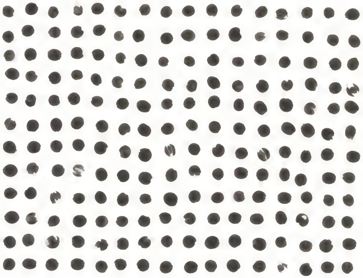


Fig. 2

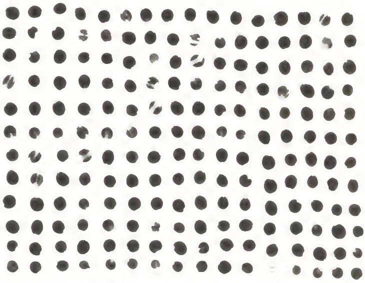


Fig. 3

EXPLANATION OF PLATE XIII

Fig. 1

Radiograph of sorghum from the test jars at 15 percent moisture treated with 150 pounds of the protectant per 1000 bushels infested with the granary weevil.

Fig. 2

Radiograph of sorghum from the test jars at 15 percent moisture treated with 200 pounds of the protectant per 1000 bushels infested with the granary weevil.

Fig. 3

Radiograph of sorghum from the test jars at 15 percent moisture treated with 250 pounds of the protectant per 1000 bushels infested with the granary weevil.

PLATE XIII

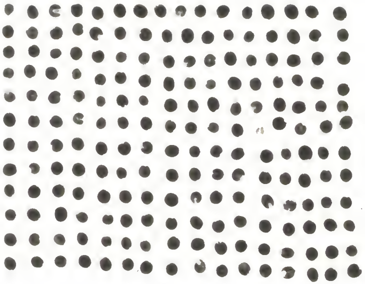


Fig. 1

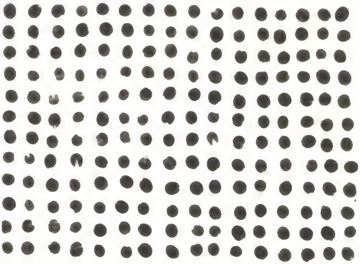


Fig. 2

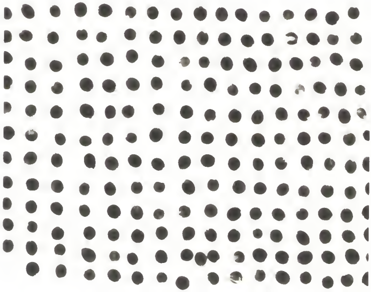


Fig. 3

EXPLANATION OF PLATE XIV

Fig. 1

Radiograph of insect-free corn stock prior to infestation with the granary weevil showing a few kernels which had been attacked by the Angoumois grain moth.

Fig. 2

Radiograph of corn from the control jars with a moisture content of 15 percent severely infested with the granary weevil.

PLATE XIV

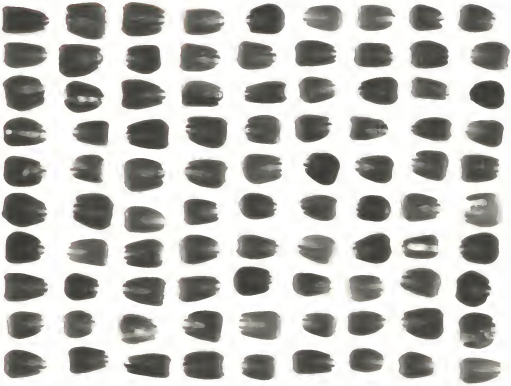


Fig. 1

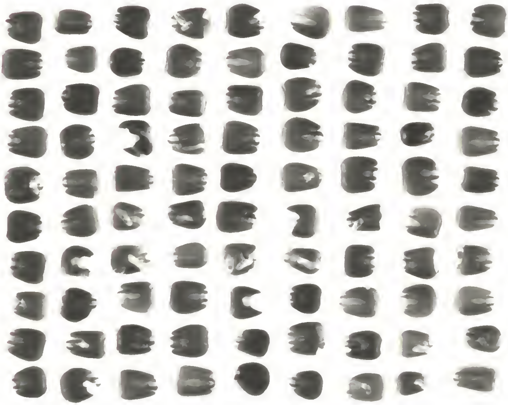


Fig. 2

EXPLANATION OF PLATE XV

Fig. 1

Radiograph of corn from the test jars at 15 percent moisture treated with 75 pounds of the protectant per 1000 bushels infested with the granary weevil.

Fig. 2

Radiograph of corn from the test jars at 15 percent moisture treated with 100 pounds of the protectant per 1000 bushels infested with the granary weevil.

PLATE XV

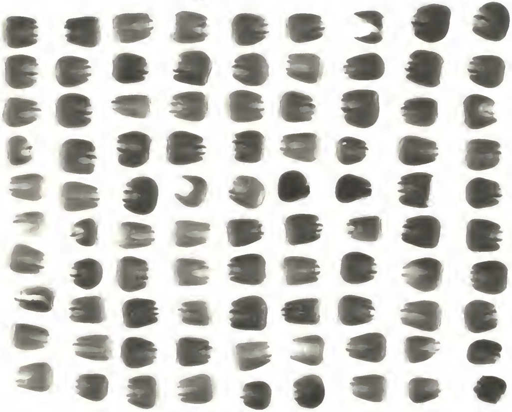


Fig. 1

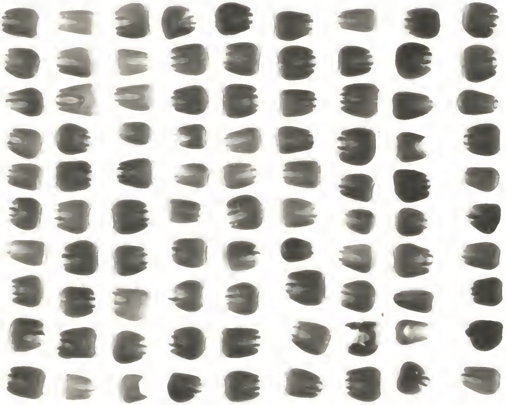


Fig. 2

The Effectiveness of Pyrenone Grain Protectant on Shelled Corn of Different Moisture Contents at Different Temperatures for Varying Lengths of Time

Shelled corn at 11 and 14 percent moisture levels was treated with the protectant at the rate of 75 pounds per 1000 bushels and stored at approximately 45 and 80 degrees Fahrenheit for a period of two, four, and six months. At the end of the storage period, samples of the corn were exposed to granary weevils, rice weevils, flat grain beetles and sawtoothed grain beetles. The mortality of the four test species was 100 percent for every combination of storage conditions. The control jars showed mortalities comparable to those found in the previous series. The mortality of the insects in the control jars decreased as the moisture content of the corn increased.

No reproduction was found in any of the treated corn and the reproduction rate in the control jars varied with the moisture content. The rate of reproduction increased steadily as the moisture content increased.

The results of this series of tests are shown in Tables 10 through 13.

Table 10. The effectiveness of Pyrenone Grain Protectant applied at the rate of 75 pounds per 1000 bushels against the rice weevil in shelled corn with the moisture contents of 11 and 14 percent stored for varying lengths of time at different temperatures.

Moisture content	Temperature of storage degrees Fahrenheit	Percent Mortality after storage 2 months	4 months	6 months
11 percent	45	100	100	100
Control	45	12	14	10
11 percent	80	100	100	100
Control	80	13	12	14
14 percent	45	100	100	100
Control	45	4	3	4
14 percent	80	100	100	100
Control	80	3	5	3

Table 11. The effectiveness of Pyrenone Grain Protectant applied at the rate of 75 pounds per 1000 bushels against the granary weevil in shelled corn with the moisture contents of 11 and 14 percent stored for varying lengths of time at different temperatures.

Moisture content	Temperature of storage degrees Fahrenheit	Percent Mortality after storage 2 months	4 months	6 months
11 percent	45	100	100	100
Control	45	9	10	11
11 percent	80	100	100	100
Control	80	8	10	9
14 percent	45	100	100	100
Control	45	2	2	1
14 percent	80	100	100	100
Control	80	1	3	2

Table 12. The effectiveness of Pyrenone Grain Protectant applied at the rate of 75 pounds per 1000 bushels against the flat grain beetle in shelled corn with the moisture contents of 11 and 14 percent stored for varying lengths of time at different temperatures.

Moisture content	Temperature of storage degrees Fahrenheit	Percent Mortality after storage		
		2 months	4 months	6 months
11 percent	45	100	100	100
Control	45	9	10	10
11 percent	80	100	100	100
Control	80	11	8	10
14 percent	45	100	100	100
Control	45	3	2	1
14 percent	80	100	100	100
Control	80	1	2	2

Table 13. The effectiveness of Pyrenone Grain Protectant applied at the rate of 75 pounds per 1000 bushels against the sawtoothed grain beetle in shelled corn with the moisture contents of 11 and 14 percent stored for varying lengths of time at different temperatures.

Moisture content	Temperature of storage degrees Fahrenheit	Percent Mortality after storage		
		2 months	4 months	6 months
11 percent	45	100	100	100
Control	45	7	9	8
11 percent	80	100	100	100
Control	80	8	7	7
14 percent	45	100	100	100
Control	45	3	2	2
14 percent	80	100	100	100
Control	80	2	1	2

DISCUSSION OF EXPERIMENTAL RESULTS

The Effectiveness of the Protectant Against the Rice Weevil and the Granary Weevil

The experimental results indicated that under the conditions of the laboratory tests, the rice weevil is easily controlled in shelled corn at a dosage of less than the recommended dosage of 100 pounds per 1000 bushels. Complete control was obtained with a dosage of 50 pounds of the protectant per 1000 bushels at all moisture levels.

Where the dosage level failed to give complete control, the moisture content of the corn modified the mortality. The increase in moisture content made the grain more favorable for the insects and because of improved conditions in the environment, a greater percentage of the insects were able to survive. This effect of moisture was observed in shelled corn treated with the protectant at a rate of 25 pounds per 1000 bushels.

Control of the rice weevil in sorghum was not as successful as the control in shelled corn. The moisture content of the sorghum showed a definite effect on the results in all of the tests.

The effectiveness of the protectant was the highest at the lowest level of moisture in the grain. As the moisture content increased, the effectiveness decreased. The rice weevils in the 11 percent moisture sorghum were completely controlled by a dosage of 50 pounds per 1000 bushels and above. Complete control was not obtained at any dosage level in sorghum with moisture contents of 12 percent and above.

The effectiveness of the protectant increased in each moisture level with each increase in dosage, but even the highest dosage used, 250 pounds per 1000 bushels, failed to give complete control in all but the 11 percent sorghum.

The granary weevil was completely controlled in the shelled corn at all moisture levels by a dosage of 75 pounds per 1000 bushels and above. The two lower dosages failed to give good control, but the mortalities increased substantially in the corn at all moisture levels as the dosage was increased.

The results of the tests against the granary weevil in sorghum showed that control was difficult. Complete control of this insect was not obtained in any of the moisture levels with any dosage used.

The three lower moisture levels showed mortalities above 90 percent, but with each increase in moisture content, the amount of protectant needed to give mortalities of 90 percent or above also increased. The highest mortality was obtained in the 11 percent sorghum with a dosage of 150 pounds per 1000 bushels and above.

The mortalities decreased successively as the moisture content increased. The mortalities for all dosage levels were lower in every case than the mortalities obtained by the corresponding dosage in the sorghum of 1 percent higher moisture.

Control of the granary weevil in 14 and 15 percent moisture sorghum did not reach 90 percent at any dosage level used in the tests.

The control jars containing the rice weevil and the granary weevil showed the effects of moisture content of the grain on the insects. The mortalities of the insects decreased as the moisture content increased. The relatively high natural mortality of these insects in the low moisture grain indicates that this factor plays an important part in the protection of the grain from infestation by these insects. Effective control was obtained in the tests combining low moisture content grain and sufficient amounts of protectant.

The mortalities obtained in both the treated and untreated grain indicate that the granary weevil is somewhat more resistant to the effects of the protectant and also was able to live in grain with low moisture contents considerably better than the rice weevil.

The Effectiveness of the Protectant Against the Flat Grain Beetle and the Sawtoothed Grain Beetle

Control of the flat grain beetle and the sawtoothed grain beetle in both grains was successful. Dosages of 50 pounds per 1000 bushels completely controlled both insects in the shelled corn.

The flat grain beetle was controlled to a higher degree than the sawtoothed grain beetle in shelled corn at a dosage of 25 pounds per 1000 bushels. At this dosage, the moisture content of the grain showed a considerable effect.

Both insects were completely controlled by the recommended dosage of 100 pounds per 1000 bushels in the sorghum. The results at dosages below the recommended dosage followed a definite pattern related to the moisture content of the grain and dosage.

The flat grain beetle showed mortalities of above 90 percent in the 11 and 12 percent sorghum and a somewhat lower mortality in the 13 percent moisture grain. The mortalities in the 14 and 15 percent sorghum decreased considerably and the protectant was almost completely ineffective against this insect at the two lower dosages. The mortalities obtained in the 11 and 12 percent moisture sorghum followed quite closely, as did the mortalities in the 14 and 15 percent moisture sorghum. The mortalities in the 13 percent grain were rather widely separated from the other two groups and fell between the high and the low groups. This indicated that this moisture level fell on the borderline as far as the effectiveness of the protectant was concerned in the dosages below 100 pounds per 1000 bushels, although it showed a tendency to approach satisfactory control.

The mortalities of the sawtoothed grain beetle followed a close pattern in the dosages below 100 pounds per 1000 bushels. The moisture content of the sorghum showed its greatest effect at a dosage of 50 pounds per 1000 bushels. At this dosage, the mortalities in the 11 and 12 percent moisture sorghum were considerably higher than those in the other three levels of moisture. A lesser effect was noted at a dosage of 75 pounds per 1000 bushels and no effect was seen at higher dosages.

The mortality of the flat grain beetle and the sawtoothed grain beetle in the control jars showed the effect of moisture content on the survival of both insects. As the moisture content increased, the mortality of the insects decreased. In the case of both the treated and untreated sorghum, the sawtoothed grain beetle showed more resistance to the protectant and moisture conditions. This difference was not as marked as in the case of the rice and granary weevils.

The results of this series of tests showed that as the moisture content in both grains increased, the mortalities of all the test insects successively decreased in each dosage category. The results also showed the mortalities of the granary weevil and the sawtoothed grain beetle were below those of the rice weevil and the flat grain beetle in every dosage category of each moisture level in both grains.

The Effect of the Protectant on the Reproduction of the Test Insects

The reproduction of each test insect in the treated grain followed a similar pattern. No reproduction was found in any treated grain of any moisture content that showed a mortality of 90 percent or above. This figure provided a sharp line of distinction and the results agreed with this dividing line all through the tests.

As the moisture content increased in both grains, the reproduction increased in each particular dosage category showing test insect mortality below 90 percent. At the same time, as the dosage was increased, the reproduction in each moisture level decreased. Reproduction in any particular dosage level was always higher as the moisture content of the grain in that category increased.

The radiographs of the sorghum and corn infested with the rice and granary weevil were included to illustrate the effects of increased dosage on the rate of reproduction. The number of kernels in each individual radiograph are not the same and definite figures cannot be taken and compared, but the radiographs do follow the same pattern in showing a decrease in reproduction of these insects as the dosage was increased as shown by the count of insects found following the additional period of storage.

The Effect of Storage at Different Temperatures on the Protectant

The tests showed no decrease in the effectiveness of the protectant when used on corn stored for varying lengths of time and at different temperatures. The dosage, 75 pounds per 1000 bushels, gave 100 percent control of all four test insects in all the tests. This complete control of all four species was also obtained in the shelled corn under the conditions of the first series of tests. The length of time the grain was stored and the temperature of storage had no effect on the effectiveness of the protectant in this series of tests. The moisture content had no effect on the effectiveness as measured by this test.

No deterioration of the 14 percent moisture corn was found as measured by signs of heating or musty odors that was held at 45 degrees Fahrenheit for six months. The corn stored at 80 degrees Fahrenheit for six months appeared to be beginning to go out of condition due to heating. This had no measurable effect on the test insects introduced following the storage period as the control jars showed the survival to be comparable to that of the control jars held at 45 degrees Fahrenheit for the same period of time. This appearance of heating in the high moisture corn indicates that the protectant has no value in suppressing or protecting high moisture corn from heating from causes other than the heating caused by insect activity.

The results of this work agree with similar work conducted by Parkin (1951), Goodwin-Bailey (1952), Watts and Berlin (1950), and Wilbur (1952) in that dusts containing pyrethrins and piperonyl butoxide are effective against the insects used. These other studies were carried out, however, using wheat as the test grain whereas corn and sorghum were used in this work.

The differences found between the two grains as shown by the differences in effectiveness of the protectant indicate that more work is needed in this particular phase of the problem. Further laboratory tests should be conducted as well as field trials to determine the various factors behind the relatively poor results against the rice and granary weevils in sorghum as shown by this work.

The results indicate that the protectant is a very effective material with which to protect shelled corn from the infestation by the four insects used in this work. The results also indicate that while the protectant is effective against the flat grain beetle and the sawtoothed grain beetle in sorghum, infestations of the rice and granary weevil cannot be successfully controlled by amounts of the protectant used in these tests.

SUMMARY AND CONCLUSIONS

Shelled corn and sorghum at five moisture contents were treated with 10 dosage levels of Pyrenone Grain Protectant. Four test species, the rice and granary weevils, the flat grain beetle, and the sawtoothed grain beetle, were exposed to the treated grain for a period of 21 days. The mortalities of the insects were determined, as well as the extent of reproduction in the treated grain. Reproduction was determined following an additional storage period of 31 days.

Shelled corn at two levels of moisture were treated with the protectant at a dosage of 75 pounds per 1000 bushels and held in storage for varying lengths of time at different temperatures. Following the storage period, the grain infested with the test insects and held for 21 days. The mortalities and amount of reproduction were determined following the exposure periods.

The conclusions based on this work are as follows:

1. The protectant was completely effective on shelled corn against all test species at all moisture levels at dosages below the recommended dosage of 100 pounds per 1000 bushels. The dosage of 25 pounds per 1000 bushels was the only one not giving good control.

2. The protectant was completely effective against the flat grain beetle and the sawtoothed grain beetle in sorghum at all moisture levels at the recommended dosage and above.

3. Complete control of the rice weevil was obtained by dosages of 50 pounds per 1000 bushels and above in the sorghum with 11 percent moisture. The effectiveness decreased steadily as the moisture content increased.

4. Complete control of the granary weevil was not obtained with any dosage level at any moisture content. Mortalities of 90 percent or above were obtained with dosages well above the recommended dosage in the low moisture sorghum. The effectiveness decreased rapidly as the moisture content increased.

5. The granary weevil and the sawtoothed grain beetle were more resistant to the effects of the protectant and moisture conditions in both grains than the rice weevil and the flat grain beetle.

6. Reproduction of all test species occurred in the treated samples where the mortality was below 90 percent. The rate of reproduction increased with each increase in moisture content.

7. The protectant showed no decrease in effectiveness when applied to shelled corn and stored for as long as six months. The period of storage at different temperatures did not affect the effectiveness of the protectant.

8. The protectant will not protect shelled corn at a high moisture content from heating when it is stored at a temperature of 80 degrees Fahrenheit for a period of six months.

ACKNOWLEDGMENTS

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THE EFFECTIVENESS OF PYRENONE GRAIN PROTECTANT AGAINST FOUR SPECIES OF GRAIN INFESTING INSECTS WHEN APPLIED TO SHELLED CORN AND SORGHUM

by

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B. S., Kansas State College
of Agriculture and Applied Science, 1950

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requirements for the degree

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1953

Pyrenone Grain Protectant has recently been introduced into the grain industry for the protection of stored grain from insect infestation. This protectant material is recommended for use on all grains except wheat and is used at the rate of 100 pounds per 1000 bushels of grain. The insecticidal ingredients in the protectant are piperonyl butoxide and pyrethrins in a ratio of 16:1 and the carrier is fibrous talc.

Because of the recommendations that the protectant may be used on all grains with the exception of wheat, it was desired to know whether the protectant was equally effective on grain with different properties.

Shelled yellow corn and sorghum were selected for the tests. Each grain was tested at five moisture levels, 11, 12, 13, 14, and 15 percent. The protectant was applied to the grain at 10 dosage levels, 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 pounds per 1000 bushels.

Four species of test insects were used throughout the tests to measure the effectiveness of the protectant. The species were the rice weevil, _Sitophilus oryza_ (L.); the granary weevil, _Sitophilus granarius_ (L.); the flat grain beetle, _Laemopholoeus_ spp., and the sawtoothed grain beetle, _Oryzaephilus surinamensis_ (L.).

The grain was adjusted to the proper moisture content, treated with the protectant, and infested with 50 adults of each test species. The treated and infested grain was then held for 21 days at 80 degrees Fahrenheit. Mortalities were determined following the exposure period. The test insects were removed from the grain and it was held for an additional period of 31 days to determine the extent of reproduction of each species.

Another series of tests were made to determine the effect of time and temperature of storage on the protectant on shelled corn. These tests were made on corn with moisture contents of 11 and 14 percent and treated with the protectant at the rate of 75 pounds per 1000 bushels. The treated grain was stored at temperatures of 45 and 80 degrees Fahrenheit for periods of two, four, and six months. After each storage period, the corn was infested with the four test species and held for 21 days. This series of tests was made in the same way as the first series, except that the treated grain was held for varying lengths of time before infestation with the test insects.

The results of the first series of tests showed that the protectant was quite effective against all the test species at dosages below the recommended dosage. The moisture content did not appear to affect the results of the tests on corn. Sorghum showed a considerable variation in the results. The flat grain beetle and the sawtoothed grain beetle were completely controlled in all moisture levels of sorghum at the recommended dosage and above.

The rice weevil was completely controlled in 11 percent moisture sorghum with dosages of 50 pounds per 1000 bushels and above. As the moisture content increased above 11 percent, the effectiveness of the protectant dropped off and satisfactory control was not obtained.

The granary weevil was not controlled effectively at any moisture level in the sorghum. Mortalities above 90 percent were obtained with dosages well above the recommended dosage, but the effectiveness decreased rapidly with each increase in moisture content.

Based on these laboratory tests, the protectant will give satisfactory control of all the test insects in shelled corn at each of the five moisture levels, but will not give satisfactory results against the rice and granary weevils in sorghum, however, control of the rice weevil may be obtained in 11 percent moisture sorghum.

The reproduction of the test insects in each grain followed a definite pattern in this series of tests. No reproduction was found in any treated grain that had a mortality of the original insects of 90 percent or above. Below this level of mortality, reproduction was found and it increased as the mortality decreased and the moisture content of the grain increased.

The granary weevil and the sawtoothed grain beetle were more resistant to the effects of the protectant and the moisture conditions of the grain than the rice weevil and the flat grain beetle.

X-rays taken of the treated corn and sorghum showed the internal infestation of the rice and granary weevils followed a pattern related to the mortality of these insects in the treated grain. The X-rays were not included for the purpose of drawing numerical conclusions, but only for illustrative purposes. The moisture level of 15 percent was the only one subjected to X-ray.

The protectant showed no decrease in effectiveness when applied to the shelled corn and stored for varying lengths of time. The results of the entire series showed the control to be 100 percent. These results agreed with the ones obtained in the first series of tests with corn at moisture levels of 11 and 14 percent.

No reproduction of the test insects was found in any of this test grain, and this also agreed with the results of the first tests.

The protectant did not protect high moisture corn from heating over a storage period of six months when stored at a temperature of 80 degrees Fahrenheit. Heating was not severe and only appeared in the 14 percent moisture corn following storage for six months. This heating did not appear to have any effect on the test insects as the control samples showed active and increasing infestation.

Further tests and investigations are needed, both in the laboratory and field. The protectant shows excellent results when applied to shelled corn, but the results obtained with sorghum indicate that it is not too effective or that other methods need to be worked out for the protection of sorghum using the grain protectant.