A LIQUID GRAIN PROTECTANT CONTAINING PYRETHRINS SYNERGIZED BY PIPERONYL BUTOXIDE AND ITS EFFECT UPON DEVELOPMENT OF CERTAIN INSECT POPULATIONS IN SORGHUM GRAINS

by

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INTRODUCTION

Protecting stored grain against insect infestation has been a problem for centuries. Through research, new and better methods of controlling stored grain insects are being developed.

In spite of the many new materials that are effective in ridding grain of insects, the problem of insects in stored grain is still one of major importance since a large amount of grain produced each year is destroyed by insects. Cotton (1948) stated that the total loss in caloric value of grain lost to insects would supply a major part of the diet of 360,000,000 adult persons for one year. It would appreciably supplement the diet of 1,000,000,000 adult persons whose diet is now deficient.

Insects destroy at least 5 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 loss of stored grain to insects in the United States is staggering. According to Cotton and Ashby (1952), 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 9 percent per month.

The control of insects in stored grain with protectants is not a new idea. Powders, both poisonous and non-poisonous have been used for this purpose for many years. Protectant powders containing pyrethins and piperonyl butoxide have given good results when applied to wheat in farm storage, according to Wilbur (1952).

In addition to protective powders, protective sprays also have been tested. Among the protective sprays, the Douglas Chemical Company research staff developed a formulation of pyrethrins and piperonyl butoxide in solution in a volatile carrier called "TETRAKOTE". This product has been tested in the Stored Products Insect Laboratory at Kansas State College and field tested in Harvey County and Allen County, Kansas, in 1952, 1954 and 1955 under the supervision of Professor Donald A. Wilbur of the Kansas Agricultural Experiment Station. Generally favorable results were obtained in the tests using farm-stored wheat and barley as test grains.

This study presents the results of laboratory work on the toxic effectiveness of TETRAKOTE when applied to sorghum grains of various kernel characteristics and moisture contents to six species of grain-infesting insects. Sorghum was chosen for testing, not only because little work with protectants has been done with it, but also because different sorghum varieties have kernel characteristics that vary appreciably from one another in their chemical and physical structure. It should be noted that this laboratory test evaluates the toxic effectiveness of the product. Any repellent action of the protectant is not considered. The work was conducted in the Department of Entomology's Stored Products Insect Laboratory at Kansas State College.

REVIEW OF LITERATURE

Control of grain-infesting insects with powders, both toxic and non-toxic, has been attempted for many years. Parkin (1944) reported the use of flint, felspar, limonite, and anhydrite against the granary weevil.

Cotton and Ashby (1952) reported that powders of finely divided silica gel, rock phosphates, precipitated chalk, magnesium and aluminum oxides have been successfully used. One part powder per 1000 parts of grain by weight may be used if the particle size is one micron or less in size.

Parkin (1944) pointed out that the mode of action of the inert powders is not clearly understood. He suggested that there are three possible effects that they may have on the insects. The first is the adhesion of the particles to the body surface, especially to the intersegmental membranes and joints of the limbs. Their presence in these locations on the insect may cause hindrance of movement which could affect copulation and oviposition. While this action might restrict the spread of the insect, it cannot be regarded as the cause of death. A second possible action is to damage or to stop the mouth parts. If this should occur, starvation would result. The most probable explanation of the action of powders is in 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.

Stored grain insects have been controlled by the use of poisonous powders. According to Cotton and Ashby (1952), such materials act independently of the moisture content of the grain. These authors stated that lindane is effective at one part per million and DDT at 15 parts per million. The use of these insecticides is restricted to seeds because of their toxicity to man and animal.

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

Sarles et al. (1949) reported that piperonyl butoxide would be expected to be only acutely toxic to warm-blooded animals when ingested in amounts that would represent a very high dosage.

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

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

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

Parkins noted a reduction in emergence of granary weevils when small quantities of the insecticide were used. 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 oviposite, 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 two pounds per 200 pounds of grain. Pyrethrum alone was applied at one pound per 200 pounds of grain.

According to Goodwin-Bailey and Holborn (1952), wheat treated with a powder containing 0.04 percent pyrethrins and 0.8 percent piperonyl butoxide at one pound per 300 pounds of wheat was protected for a period of 11 months when granary weevils and saw-toothed grain beetles were the test insects. The protection was equal over the 11-month storage period, but saw-toothed grain beetles were less resistant to the powder than granary weevils.

Insect population increase was slight in wheat treated with a powder 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 protectant containing 1.1 percent piperonyl butoxide and 0.08 percent pyrethrins had an appreciable effect on the toxicity of the powder against rice weevils and saw-toothed grain beetles in laboratory tests. With an increase in the moisture content of the grain, the toxicity of the protectant decreased. Field tests using this same powder at 75 pounds per 1000 bushels resulted in complete protection from grain-infesting insects of wheat at moisture contents of between 13 and 15 percent. Field conditions provided an opportunity for the repellent characteristics of the powders to act, whereas the laboratory tests did not.

In farm storage tests conducted in Allen County and in Montgomery County, Kansas, during 1955, Wilbur and McGregor[1] found that wheat and barley treated with protectant sprays containing pyrethrins and piperonyl butoxide were protected from grain-damaging insects except when they were stored in especially unsanitary granaries. The high moisture prevalent in the test grains and the wooden granaries provided rigorous tests for the protective spray. The application rates recommended by the manufacturers were adequate for all but the most unsanitary conditions. Where especially favorable grain storage conditions

[1] Unpublished; mimeographed reports given cooperators.

prevailed, dosage rates appreciably lower than recommended by manufacturers were adequate.

METHODS AND MATERIALS

Liquid Protectant (TETRAKOTE)

The liquid grain protectant used in this experiment was the commercial formulation labeled TETRAKOTE manufactured by the Douglas Chemical Company (Plate I). This formulation is marketed in one-gallon, five-gallon, or 55-gallon drums. Its contents given on the label include:

Active ingredients: 97%

Inert ingredients: 3%

The technical piperonyl butoxide consists of (butylcarbityl) (6 propyl piperonyl) ether plus related compounds.

Pyrethrins with the synergist, piperonyl butoxide, have been used for several years as the toxic agents of protectant powders. Years of research have shown the protectant powders containing pyrethrins and piperonyl butoxide to be successful in controlling certain grain-infesting insects and to be non-toxic to warm-blooded animals in dosages many times that needed to control the insects.

The liquid protectant discussed in this report likewise is relatively non-toxic to man or animal when applied to grain as recommended by the manufacturers.

The dosage rates used in the laboratory tests reported in this paper were as follows:

EXPLANATION OF PLATE I

A gallon of TETRAKOTE, the commercial liquid grain protectant used in this study.

PLATE I

Gal./1000 bu.	ml/1000 g	Residue* pyrethrins ppm
1.5	0.24	0.84
2.0	0.33	1.12
2.5	0.41	1.40
3.0	0.49	1.68
3.5	0.58	1.96

* Provided by Ward Graham, Technical Director, Douglas Chemical Company.

Test Insects

The test insects consisted of six species of grain-infesting insects found throughout the United States. They included: Sitophilus oryzae (L.), rice weevil; Sitophilus granarius (L.), granary weevil; Oryzaephilus surinamenses (L.), saw-toothed grain beetle; Laemophloeus spp. grain beetle; Rhizopertha dominica (Fab.), lesser grain borer; and Tribolium confusum Duv., confused flour beetle. The insects were reared in the constant temperature room of the Stored Products Insect Laboratory of the Department of Entomology.

The rice weevils, granary weevils, and the lesser grain borers were reared separately in culture media of hard red winter wheat at a moisture content of 13.5 percent. The grain beetles and the saw-toothed grain beetles were reared in a media of rolled oats of undetermined moisture content. The confused flour beetles were reared in a media of 75 percent patent flour and 25 percent shorts. The temperature in the culture room was maintained at 80° F. and the relative humidity at approximately 70 percent.

Wheat was infested with adult rice weevils and granary weevils of one to four weeks old for seven days. Then the adults were removed by screening and the wheat returned to the rearing room. Cultures of lesser grain borers, saw-toothed grain beetles, grain beetles, and confused flour beetles were reworked periodically and were of indeterminate age.

Preparation of the Grain

The three varieties of sorghums treated were Colby, Westland, and Martin. These were selected because of their kernel characteristics: Colby has a soft kernel; Westland an intermediate hard kernel; and Martin a rather hard kernel.

Colby sorghum grain was certified seed from the 1955 crop and was secured from the Colby Experiment Station at Colby, Kansas. Westland, also certified and from the 1955 crop, was obtained from the Gerald G. Finely farm at Garden City, Kansas. Martin was secured from the Schwab Brothers farm near Manhattan, Kansas. It was uncertified and of the 1955 crop.

The first step in preparing the grain for the tests was to place it in a refrigerator with the thermostat at -20° F. for six days. This was to rid the grain of all infestation. The grain was then stored in steel drums with relatively tight lids clamped in place.

For each of the nine tests, the grain to be used was weighed and screened through a number 10 screen (Fig. 1, Plate II). Screening removed dead insects, weed seeds, and most of the

EXPLANATION OF PLATE II

Fig. 1. The Rotomatic sifter used to separate the insects from the grain.

Fig. 2. The Steinlite moisture tester used to determine the moisture content of the grain.

PLATE II

Fig. 1

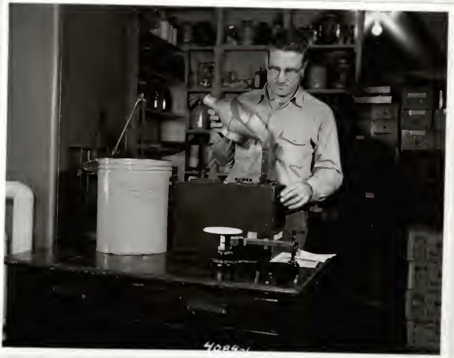

Fig. 2

damaged kernels.

The grain was then placed in a clean 50-pound lard can, covered with a tight lid, and set in the constant temperature room for 48 hours to standardize the temperature. When this was accomplished, the grain moisture was determined using a Steinlite Moisture Tester (Fig. 2, Plate II). For greater accuracy, a moisture reading was taken on five samples of grain, and the average moisture content determined. If the moisture was too high for the test, the grain was dried out by placing a fan so that it would blow warm air over the grain (Fig. 2, Plate III). When the moisture was too low, distilled water was added to bring the moisture content up to the desired level.

The adjustment of the moisture content of grain was accomplished by a method employed by Cotton and illustrated by the following example:

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

Procedure

$$100 - 10 = 90$$
$$100 - 11 = 89$$
$$90 \div 89 = 1.01123$$

The first digit which is always 1, is dropped. The remainder of the quotient is used as the multiple factor. Thus, 50,000 g 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 grain was mixed by

EXPLANATION OF PLATE III

Fig. 1. The author preparing to add distilled water to the test grain to raise its moisture content.

Fig. 2. Sorghum grain spread on the table in front of a fan to reduce the moisture content.

PLATE III

Fig. 1.

Fig. 2

hand, the lid replaced, and the can of grain rolled on the floor to get a good distribution of the moisture. Masking tape was then placed around the lid to keep any water vapor from escaping. The grain was mixed several times a day for five days by rolling and shaking the can of grain.

The amount of dockage in the test grain was determined by weighing 10 random samples of 10 g each (Fig. 2, Plate V) and picking out all of the cracked and damaged kernels and any foreign material present. This dockage was then weighed and the percentage of dockage calculated. The dockage ranged from 2.2 to 3.0 percent.

Application of the Liquid Protectant

Nine tests consisting of three varieties of sorghum at three moisture levels were made for each of five dosages and a control for each.

In preparing each test, 48 wide-mouthed quart jars and 12 wide-mouthed gallon mixing jars were washed, rinsed, and placed in a thermostatically controlled oven with the temperature set at 400°F. for 30 minutes. When the jars were removed, they were covered to avoid contamination.

The sorghum grain, which previously had been tempered to the desired moisture content, was weighed into 1000 g lots and placed in the 12 one-gallon mixing jars which were marked according to the dosages they were to receive.

The liquid protectant was applied to the grain with a 1 ml pipette, graduated to 0.01 ml (Fig. 1, Plate IV). Extreme care

EXPLANATION OF PLATE IV

Fig. 1. Author treating the test grain with TETRAKOTE.

Fig. 2. Mixing the treated grain on the mechanical tumbler.

PLATE IV

Fig. 1

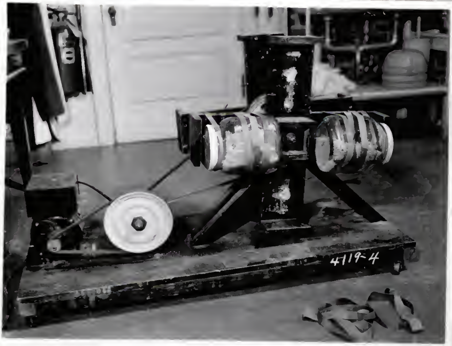

Fig. 2

was exercised in placing the liquid protectant on the inner surface of the mixing jar and not directly on the grain. After the introduction of the protectant, the cover was placed on the mixing jar and the jar agitated to initiate primary mixing. The mixing jar was then placed on the mechanical tumbler (Fig. 2, Plate IV) for 20 minutes.

The grain was then removed from the mixing jar and placed on clean paper to air for one hour. The airing permitted the ethylene tetrachloride, which acts as a carrier for the pyrethrins, to evaporate and disappear.

The grain, at the end of an hour, was divided into four equal lots and placed in wide-mouthed quart jars which previously had been marked for identification. Each jar was labeled with an experiment number which consisted of the year, month, and day the experiment was started, the series letter A or B, the dosage used, and the replication number.

Infestation of the Treated Grain with the Test Insects

Since this study was initiated to find the toxic effectiveness of TETRAKOTE on three varieties of sorghum at three moisture levels and against six species of insects, it was necessary to run each of the nine tests in two parts. Each of the four replications of each dosage of series A received 25 each of rice weevils, saw-toothed grain beetles, and lesser grain borers. Series B of each test received 25 each of granary weevils, flat grain beetles, and confused flour beetles.

The test insects were screened from the culture media and counted prior to treating the grain with the liquid protectant. Salve tins were used to hold the insects until they were placed in the test grain. Only 25 insects were placed in each salve tin.

In order to avoid error, the four replications of a given dosage were placed on a table and the three salve tins containing the test insects that were to be introduced into the test grain were placed in front of each jar. The insects were then introduced into the grain. After each jar had been infested, the lid was placed 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 the insects and not have the jar completely air tight.

As infestation was completed, the infested test grain was placed in the culture room where the temperature was held at 80° F. and the relative humidity at approximately 70 percent.

Determination of Insect Survival and Reproduction

When the exposure period of 14 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 replaced in the jars for further observation.

The adult insects, screened from each sample, were picked up with the aspirator (Fig. 1, Plate V) and the number of alive and dead insects of each species was determined and recorded. Insects that showed any movement were considered alive. The

EXPLANATION OF PLATE V

Fig. 1. Author picking up insects with the aspirator.

Fig. 2. Weighing out 100-gram samples of test grain with the balance scales to check the percentage of dockage in the grain.

PLATE V

Fig. 1

Fig. 2

insects and screenings were discarded and the test grain returned to the rearing room for 35 days to develop progeny.

On the 35th day, the grain was removed from the rearing room and the number of alive and dead progeny was recorded.

A moisture test was made on one test jar of grain from each dosage used to determine changes of the moisture level in the grain during the test.

EXPERIMENTAL RESULTS

The Toxic Effectiveness of TETRAKOTE on the Test Insects in Three Varieties of Sorghum at Three Moisture Levels

In evaluating the data from the various tests conducted in this study, several variables were considered, the most important of which were six species of grain-infesting insects and three varieties of sorghum grain at three moisture levels. The sorghum grain varieties were Colby, Westland, and Martin, and the moisture contents were 11, 13, and 15 percent. Complete results of the toxicity tests on one variety are presented before another variety is discussed.

Colby Sorghum Grain. The rice and granary weevils (Table 1) failed to survive in the controls of the Colby tests in sufficient numbers to determine the toxic effect of the protectant on the insects in the grain treated at the five dosages. In order that supporting evidence could be presented, a special test was made to determine the effect of untreated Colby sorghum grain upon the longevity of the six species of test insects used.

Colby sorghum grain of 11, 13, and 15 percent moisture was exposed to the six species of test insects for 3, 6, 9, 12, and 15 days. After the exposure period, the insects were screened from the grain and the number of alive and dead insects determined and recorded. The grain was then placed in the rearing room for 35 days to develop progeny. On the 35th day the grain was screened and the number of progeny determined. Data in Table 10 record the percentage mortality of adults when exposed to the grain of various moisture levels and exposure time.

The mortality was high for rice weevils and granary weevils in all three moisture levels. These data indicate that one or more factors are present in Colby grain that definitely hinders weevil survival. An unknown contaminant residue on the grain appears to be out of the question since the mortality of saw-toothed grain beetles and confused flour beetles was low. Data on flat grain beetles and lesser grain borers indicated an above normal mortality which cannot be explained at present.

It should be noted in Table 11 that, as the moisture increased, oviposition increased, except for saw-toothed grain beetles which held rather constant. Although a considerable number of rice weevil adults developed after the initial screening, the number that survived after reaching the adult stage was few. The number of granary weevils to develop and to survive was greater than for rice weevils.

The reason why rice and granary weevils failed to survive and reproduce in great numbers in the Colby sorghum grain has not been determined, but it appears to be associated with a characteristic peculiar to the Colby variety. Further research along this line may reveal the unknown cause.

In discussing the experimental results of the protectant tests using the Colby sorghum grain, the data collected on the rice and granary weevil will not be discussed in this paper because of the high mortality rate in the controls (Table 1).

TETRAKOTE applied to the Colby sorghum grain of 11 percent moisture at 3.5 gallons per 1000 bushel rate resulted in 94 percent mortality for saw-toothed grain beetles. As the moisture increased, survival of saw-toothed grain beetles increased. At 15 percent moisture, a 59 percent mortality resulted at the 3.5 gallon per 1000 bushel dosage.

A 100 percent mortality of lesser grain borers was obtained at 3.5 gallon per 1000 bushel dosage on both 11 and 15 percent moisture. Three percent of the lesser grain borers survived in the 13 percent grain at the same dosage.

The 3.5 gallons per 1000 bushel dosage resulted in 100 percent mortality of flat grain beetles in 11 percent moisture. With an increase of moisture, an increase in the survival rate was noted (Table 2). The same dosage in grain of 13 and 15 percent moisture resulted in 97.8 and 85.0 percent mortality, respectively.

The application rate of 3.5 gallons per 1000 bushels on Colby grain of 11 percent moisture gave 90 percent mortality for confused flour beetles, but at moistures of 13 and 15 percent, the protectant had little effect on the beetles.

Westland Sorghum Grain. TETRAKOTE applied to Westland sorghum grain of 11 and 13 percent moisture at 1.5 and 2.5 gallons per 1000 bushels resulted in 100 percent kill of rice weevils. Only 91 percent mortality was obtained when the moisture was raised to 15 percent and the dosage to 3.5 gallons.

Data on saw-toothed grain beetles indicated that this insect was resistant to the protectant. Mortalities of 52, 75, and 42 percent were obtained in Westland sorghum grain of 11, 13, and 15 percent moisture at the 3.5 gallon dosage.

A mortality of 90 percent or more was obtained with lesser grain borers at 2.0 gallons per 1000 bushels of grain at 11, 13, and 15 percent moisture. Three gallons per 1000 bushels gave 100 percent kill in the 15 percent moisture. A complete kill was not obtained in the 11 percent grain at the 3.5 gallon dosage rate.

No granary weevils survived in the Westland sorghum grain of 11 percent moisture treated at 3.5 gallons per 1000 bushel rate. The dosage rate of 2.5 gallons was sufficient to give 100 percent kill in the 13 percent grain. When grain of 15 percent moisture was used, only 86 percent of the granary weevils were dead at the end of the 14 day exposure period when treated at the high dosage rate.

The 2.0 gallon per 1000 bushel dosage was successful in killing 100 percent of the flat grain beetles in the 11 percent grain. In 13 percent Westland, a 2.5 gallons dosage was needed to give complete kill. Only 73 percent of the flat grain beetles were dead in 15 percent grain treated at 3.5 gallons per 1000 bushels.

Confused flour beetles show considerable resistance to the protectant at all dosage levels. A mortality of 17 percent resulted at 3.5 gallons per 1000 bushels in grain of 11 percent moisture. The mortality rate of confused flour beetles in the treated grain of 13 and 15 percent moisture was extremely low when compared with the controls.

Martin Sorghum Grain. When Martin sorghum grain of 11 percent moisture was treated at 3.5 gallons per 1000 bushels, 100 percent mortality of rice weevils was obtained. At the same dosage applied to 13 percent grain, the kill was 90 percent. When the moisture content of the grain was raised to 15 percent, the mortality rate decreased to 78 percent. The data presented in Table 7 indicated rice weevils can survive in grain treated at appreciably higher rates than recommended by the manufacturer if the grain has a high moisture content.

Saw-toothed grain beetles show a progressive increase in survival as the moisture content of the grain increased. When the grain was treated at the dosages of 3.5 gallons per 1000 bushels, 98 percent mortality was obtained in 11 percent grain. At 13 percent moisture and the same dosage, 93 percent kill was recorded. A 77 percent mortality was obtained when the moisture content was raised to 15 percent.

A mortality of 95 percent or better was obtained on lesser grain borers in grain of 11, 13, and 15 percent moisture content when treated at the rate of 3.0 gallons per 1000 bushels. At 3.5 gallong per 1000 bushels, 96 percent mortality was recorded for 11 percent grain and 100 percent mortality in 13 percent grain. When 15 percent moisture was used, 98.9 percent mortality was obtained in the grain treated at the 3.5 gallon per 1000 bushel rate.

A mortality of 100 percent was recorded for granary weevils in 11 percent grain when treated at 3.5 gallons per 1000 bushels. The mortality was 96 percent when 15 percent grain was treated at the same rate.

The 60 percent mortality observed in the controls of 11 percent Martin grain indicated the necessity of high grain moisture for survival of flat grain beetles. When the 11 percent grain was treated with 3.5 gallons, a mortality of 98 percent was obtained. When the flat grain beetles were exposed to untreated grain of 13 percent moisture, only 4.5 percent mortality occurred, but with 3.5 gallons, 92 percent were killed. As the moisture content increased, the survival rate also increased (Table 8). In the 15 percent grain treated with 3.5 gallons, only 82.8 percent mortality occurred.

The results of tests using confused flour beetles as the test insect are so inconsistent that a proper explanation cannot be given without further evidence.

The Effectiveness of TETRAKOTE in Preventing Insect Reproduction

Tables 3, 6, and 9 indicate the relative effectiveness of TETRAKOTE applied to three varieties of sorghum at three moisture levels at dosages between 1.5 and 3.5 gallons per 1000 bushels in preventing the development and survival of certain grain-infesting insects in laboratory tests. More insects developed in the sorghum grain of 15 percent moisture content than in the drier grain. The high survival rate was expected in the 15 percent grain because, in most tests, more adults survived the 14-day exposure in grain with high moisture content.

The dosage of 3.5 gallons of TETRAKOTE to the Colby grain of 11 percent moisture prevented the development and survival of all the test insects except one rice weevil and two saw-toothed grain beetles (Table 3). The 2.0 gallons dosage prevented development of lesser grain borers, flat grain beetles, and confused flour beetles. Two granary weevils survived after development in the 2.0 gallon dosage rate.

In 13 percent Colby, 2.0 gallons per 1000 bushel rate resulted in high mortality of rice weevils, lesser grain borers, granary weevils, and flat grain beetles. The results obtained with saw-toothed grain beetles and confused flour beetles were somewhat irregular.

Rice weevil and flat grain beetle progeny failed to develop in the treated and untreated Westland sorghum grain of 11 percent. The 2.5 gallons per 1000 bushel rate prevented the development and survival of rice weevils, granary weevils, flat grain beetles, and the confused flour beetles. Only five saw-toothed grain beetles and nine lesser grain borers developed at this dosage.

TETRAKOTE applied at 3.5 gallons per 1000 bushels failed to prevent rice weevils, saw-toothed grain beetles, and granary weevils from developing in sizable numbers in 15 percent Westland. The 1.5 gallon dosage rate gave fair results with lesser grain borers, flat grain beetles, and confused flour beetles.

Three gallons per 1000 bushels gave good results in the 11 percent Martin sorghum grain with all test insects. The 2.5 gallon dosage gave fair results in 13 percent grain, but rice and granary weevils developed and survived in grain treated with 3.5 gallons.

Rice weevils developed in large numbers in 15 percent Martin treated with 3.5 gallons.

The 2.5 gallons dosage gave favorable results on the lesser grain borers and saw-toothed grain beetles. Only two confused flour beetles and five granary weevils developed and survived. Fourteen flat grain beetles were recorded at this dosage level and moisture content.

Table 1. The toxic effectiveness of TETRAKOTE when applied to Colby sorghum of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Rice weevil			Saw-toothed grain beetle			Lesser grain borer		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	9	89	90.0	89	11	11.0	67	21	24.0
1.5	11	1	99	99.0	59	40	40.1	12	94	88.6
2.0	11	0	79	100.0	60	41	40.6	3	91	97.0
2.5	11	0	103	100.0	24	79	76.6	1	93	99.0
3.0	11	0	101	100.0	10	89	90.0	2	89	98.0
3.5	11	0	101	100.0	6	97	94.0	0	97	100.0
0.0	13	0	99	100.0	88	8	9.6	77	9	11.1
1.5	13	0	99	100.0	90	7	8.0	22	64	73.0
2.0	13	0	100	100.0	77	23	23.0	3	97	97.0
2.5	13	0	123	100.0	81	16	16.5	3	93	97.0
3.0	13	0	98	100.0	74	23	24.0	4	88	95.6
3.5	13	0	94	100.0	34	66	66.0	3	92	97.0
0.0	15	14	84	85.0	80	18	18.4	64	21	25.0
1.5	15	2	97	98.0	71	24	25.2	35	59	62.8
2.0	15	2	95	97.9	52	30	37.0	10	86	89.0
2.5	15	0	98	100.0	40	48	54.0	3	97	97.0
3.0	15	1	98	99.0	36	61	62.0	1	98	99.0
3.5	15	0	94	100.0	40	57	59.0	0	98	100.0

Table 2. The toxic effectiveness of TETRAKOTE when applied to Colby sorghums of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Granary weevil			Flat grain beetle			Confused flour beetle		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	5	97	95.0	56	40	42.0	76	24	24.0
1.5	11	2	98	98.0	25	68	73.0	60	40	40.0
2.0	11	1	99	99.0	16	82	83.0	94	4	4.1
2.5	11	0	101	100.0	6	87	93.5	57	34	37.4
3.0	11	0	75	100.0	4	68	94.4	50	48	49.0
3.5	11	1	99	99.0	0	99	100.0	9	87	90.6
0.0	13	17	85	40.0	69	29	30.0	96	3	3.0
1.5	13	0	99	100.0	58	32	36.0	99	1	1.0
2.0	13	0	99	100.0	32	67	67.6	96	3	3.1
2.5	13	0	100	100.0	2	87	97.7	98	1	1.1
3.0	13	0	99	100.0	1	91	98.9	98	1	1.1
3.5	13	0	99	100.0	2	90	97.8	97	1	1.1
0.0	15	3	95	96.9	79	13	14.2	100	0	0.0
1.5	15	0	98	100.0	49	43	47.0	97	3	3.0
2.0	15	2	98	98.0	30	62	67.4	100	0	0.0
2.5	15	0	98	100.0	10	84	89.0	97	0	0.0
3.0	15	0	98	100.0	18	75	80.0	97	2	2.1
3.5	15	0	97	100.0	14	81	85.0	97	0	0.0

Table 3. The effectiveness of TETRAKOTE applied at rates between 1.5 and 3.5 gallons/1000 bushels in preventing the development of progeny of certain grain-infesting insects to Colby sorghum grain of 11, 13, and 15 percent moisture.

		Number of live progeny from 100 unsexed adults 35 days after removal of parents					
Dosage	Moisture	Rice weevil	Saw-toothed grain beetle	Lesser grain borer	Granary weevil	Flat grain beetle	Confused flour beetle
0.0	11	46	71	172	4	2	0
1.5	11	13	92	14	7	1	7
2.0	11	8	31	0	2	0	0
2.5	11	2	9	0	0	0	0
3.0	11	3	5	0	0	0	0
3.5	11	1	2	0	0	0	0
0.0	13	1	79	484	51	67	11
1.5	13	1	103	17	0	17	5
2.0	13	0	82	4	0	3	2
2.5	13	0	80	0	0	0	14
3.0	13	0	136	1	0	0	10
3.5	13	1	11	0	0	0	4
0.0	15	210	128	324	120	313	57
1.5	15	64	135	33	6	91	15
2.0	15	3	121	1	5	44	1
2.5	15	2	52	2	0	0	5
3.0	15	19	44	0	2	27	4
3.5	15	0	69	0	0	8	2

Table 4. The toxic effectiveness of TETRAKOTE when applied to Westland sorghum of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Rice weevil			Saw-toothed grain beetle			Lesser grain borer		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	31	65	69.7	99	1	1.0	49	14	22.3
1.5	11	1	99	99.0	94	5	5.1	49	18	27.0
2.0	11	1	97	98.9	86	14	14.0	21	63	75.0
2.5	11	0	100	100.0	79	18	18.6	17	62	78.4
3.0	11	0	100	100.0	62	25	28.8	8	86	91.4
3.5	11	0	100	100.0	47	52	52.5	5	90	94.7
0.0	13	76	11	12.0	89	7	9.0	63	13	17.0
1.5	13	0	94	100.0	82	19	18.0	21	79	79.0
2.0	13	0	100	100.0	63	35	28.0	8	90	91.0
2.5	13	0	97	100.0	55	45	45.0	6	89	93.0
3.0	13	0	99	100.0	44	49	53.0	3	97	97.3
3.5	13	0	98	100.0	23	72	75.0	0	98	100.0
0.0	15	91	7	7.2	90	8	8.2	79	13	15.0
1.5	15	27	71	62.0	66	30	32.0	16	87	85.0
2.0	15	24	71	74.0	55	27	33.0	5	98	95.0
2.5	15	15	68	81.0	57	43	43.0	4	99	96.0
3.0	15	16	112	87.5	53	25	33.0	0	95	100.0
3.5	15	7	77	91.0	49	35	42.0	0	103	100.0

Table 5. The toxic effectiveness of TETRAKOTE when applied to Westland sorghum of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Granary weevil			Flat grain beetle			Confused flour beetle		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	69	24	26.0	48	29	38.0	99	2	2.0
1.5	11	35	64	64.6	3	95	96.9	75	26	26.0
2.0	11	7	93	93.0	0	94	100.0	75	25	25.0
2.5	11	2	95	97.9	0	93	100.0	94	5	5.1
3.0	11	1	99	99.0	0	97	100.0	90	9	9.1
3.5	11	0	99	100.0	0	96	100.0	82	17	17.2
0.0	13	90	10	10.0	77	4	5.0	97	3	3.0
1.5	13	15	85	85.0	6	89	94.0	99	0	0.0
2.0	13	5	95	95.0	2	86	98.0	98	1	1.0
2.5	13	0	103	100.0	0	97	100.0	101	0	0.0
3.0	13	0	102	100.0	0	96	100.0	101	0	0.0
3.5	13	0	99	100.0	2	95	99.0	99	0	0.0
0.0	15	95	1	1.1	89	5	5.4	99	0	0.0
1.5	15	54	34	31.0	39	49	55.0	101	0	0.0
2.0	15	77	23	23.0	37	61	62.2	99	0	0.0
2.5	15	38	59	70.0	31	66	68.0	100	0	0.0
3.0	15	19	81	81.0	20	79	79.7	99	1	1.0
3.5	15	12	75	86.0	25	71	73.0	87	4	4.4

Table 6. The effectiveness of TETRAKOTE applied at rates between 1.5 and 3.5 gallons/1000 bushels in preventing the development of progeny of certain grain-infesting insects to Westland sorghum grain of 11, 13, and 15 percent moisture.

		Number of live progeny from 100 unsexed adults 35 days after removal of parents					
Dosage	Moisture	Rice weevil	Saw-toothed grain beetle	Lesser grain borer	Granary weevil	Flat grain beetle	Confused flour beetle
0.0	11	0	31	49	7	0	1
1.5	11	0	26	27	12	0	0
2.0	11	0	18	12	2	0	0
2.5	11	0	5	9	0	0	0
3.0	11	0	4	5	0	0	0
3.5	11	0	0	1	0	0	0
0.0	13	714	162	330	119	14	2
1.5	13	1	75	0	9	2	0
2.0	13	0	48	0	0	0	0
2.5	13	0	24	1	0	0	1
3.0	13	0	10	0	0	0	0
3.5	13	0	14	0	0	0	0
0.0	15	700*	181	77	3800*	320	18
1.5	15	454	90	0	717	6	0
2.0	15	432	167	2	1295*	11	0
2.5	15	264	121	0	492	2	0
3.0	15	115	87	0	161	3	0
3.5	15	57	82	0	70	0	1

* Estimate.

Table 7. The toxic effectiveness of TETRAKOTE when applied to Martin sorghum of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Rice weevil			Saw-toothed grain beetle			Lesser grain borer		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	67	31	32.3	85	15	15.0	66	31	32.0
1.5	11	37	61	62.0	63	36	36.4	50	50	50.0
2.0	11	27	73	73.0	46	53	53.5	31	68	68.6
2.5	11	6	95	94.0	33	67	66.6	11	86	88.6
3.0	11	3	96	96.9	6	95	94.0	3	94	96.9
3.5	11	0	98	100.0	1	88	98.8	3	81	96.4
0.0	13	95	4	4.1	82	15	15.5	76	9	11.6
1.5	13	77	20	20.7	67	27	29.0	14	86	86.0
2.0	13	64	31	33.0	33	64	65.9	2	97	97.9
2.5	13	40	58	58.4	12	82	87.0	1	100	99.0
3.0	13	25	73	74.4	7	86	92.4	0	101	100.0
3.5	13	9	89	90.0	6	88	93.6	0	101	100.0
0.0	15	88	10	10.3	80	5	6.0	80	0	0.0
1.5	15	86	14	14.0	70	27	28.0	38	55	59.0
2.0	15	79	17	18.0	70	30	30.0	16	81	83.5
2.5	15	77	21	21.5	67	32	32.4	10	90	90.0
3.0	15	64	33	34.0	38	62	62.0	4	93	95.8
3.5	15	21	75	78.0	22	75	77.0	1	94	98.9

Table 8. The toxic effectiveness of TETRAKOTE when applied to Martin sorghum of 11, 13, and 15 percent moisture at dosage rates between 1.5 and 3.5 gallons/1000 bushels to certain grain-infesting insects.

Dosage	Moisture	Granary weevil			Flat grain beetle			Confused flour beetle		
		live	dead	% dead	live	dead	% dead	live	dead	% dead
0.0	11	79	21	21.0	38	57	60.0	94	6	6.0
1.5	11	25	74	74.7	47	44	48.4	61	28	31.5
2.0	11	3	94	96.9	20	72	88.0	67	31	32.0
2.5	11	6	89	93.6	4	88	93.6	8	94	92.1
3.0	11	6	90	93.7	1	98	98.9	37	61	62.0
3.5	11	0	109	100.0	1	97	98.9	82	20	19.7
0.0	13	82	18	18.0	86	4	4.5	80	19	19.2
1.5	13	68	28	29.2	56	39	41.1	94	11	10.5
2.0	13	40	60	60.0	28	65	68.8	81	13	14.0
2.5	13	31	63	67.0	6	89	93.6	85	12	12.4
3.0	13	13	84	86.5	0	92	100.0	77	21	21.5
3.5	13	4	97	94.0	7	84	92.3	3	47	94.0
0.0	15	90	8	9.2	94	2	3.0	27	69	71.6
1.5	15	31	67	68.3	81	16	17.0	21	76	78.0
2.0	15	31	70	70.0	72	26	27.0	80	19	19.2
2.5	15	14	82	85.0	68	31	31.4	72	25	25.0
3.0	15	6	90	93.7	11	71	86.0	86	5	6.0
3.5	15	3	96	96.4	17	82	82.8	86	11	11.4

Table 9. The effectiveness of TETRAKOTE applied at rates between 1.5 and 3.5 gallons/1000 bushels in preventing the development of progeny of certain grain-infesting insects to Martin sorghum grain of 11, 13, and 15 percent moisture.

Dosage	Moisture	Number of live progeny from 100 unsexed adults 35 days after removal of parents					
		Rice weevil	Saw-toothed grain beetle	Lesser grain borer	Granary weevil	Flat grain beetle	Confused flour beetle
0.0	11	26	61	167	52	8	1
1.5	11	18	55	5	5	8	0
2.0	11	5	23	8	0	0	0
2.5	11	11	21	2	1	0	0
3.0	11	3	2	0	0	5	0
3.5	11	0	2	1	0	0	0
0.0	13	1023*	119	132	236	248	16
1.5	13	777	44	53	153	35	1
2.0	13	435	20	0	45	22	2
2.5	13	194	2	0	113	5	2
3.0	13	181	0	0	71	0	0
3.5	13	33	0	0	15	2	0
0.0	15	3200*	800*	600*	434	249	0
1.5	15	1200*	400*	400	137	61	0
2.0	15	800*	400*	400*	86	36	1
2.5	15	800*	0	0	5	14	2
3.0	15	760	1	0	9	1	12
3.5	15	462	2	1	0	0	4

* Estimate.

Table 10. The effect of untreated Colby sorghum grain of 11, 13, and 15 percent moisture content on the longevity of certain grain-infesting insects.

Moisture	Days after infestation	Mortality in percentage: Rice weevil	Saw-toothed grain beetle	Lesser grain borer	Granary weevil	Flat grain beetle	Confused flour beetle
11	3	84.0	4.0	20.0	74.0	12.0	0.0
11	6	100.0	0.0	23.8	85.2	47.8	4.3
11	9	100.0	4.0	43.0	83.3	48.0	0.0
11	12	100.0	0.0	35.0	87.5	68.4	0.0
11	15	100.0	11.8	62.5	90.0	60.0	4.0
13	3	75.0	0.0	10.0	60.0	4.0	4.0
13	6	92.4	0.0	20.0	100.0	21.7	4.0
13	9	100.0	0.0	26.0	100.0	9.0	0.0
13	12	92.6	8.6	33.3	100.0	21.1	0.0
13	15	100.0	11.0	45.4	77.0	28.5	0.0
15	3	70.0	3.8	15.4	79.0	4.0	4.0
15	6	88.5	0.0	21.0	96.2	22.7	0.0
15	9	100.0	0.0	20.0	100.0	28.0	0.0
15	12	100.0	14.2	53.0	95.3	4.7	0.0
15	15	100.0	8.0	36.8	95.4	9.0	0.0

Table 11. The effect of untreated Colby sorghum grain of 11, 13, and 15 percent moisture content on the reproduction and survival of certain grain infesting insects.

Moisture %	No. of days test grain was exposed to adult weevil	Number of progeny 35 days after 25 unsexed adult insects were removed											
		Rice weevil		Saw-toothed grain beetle		Lesser grain borer		Granary weevil		Flat grain beetle		Confused flour beetle	
		alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead
11	3	0	0	13	0	1	2	0	0	0	0	0	0
11	6	0	0	24	0	2	1	3	2	1	0	0	0
11	9	0	0	32	0	24	2	1	9	1	0	1	0
11	12	0	1	44	1	24	8	1	0	0	1	0	0
11	15	0	2	37	0	4	1	3	1	23	1	2	1
13	3	4	7	10	0	6	3	10	18	1	0	0	0
13	6	1	6	26	0	15	3	1	2	0	2	0	0
13	9	0	3	25	2	46	2	0	9	1	1	1	0
13	12	0	15	42	6	52	8	0	22	3	0	0	0
13	15	1	5	1	0	56	4	3	14	10	0	0	5
15	3	3	5	19	0	18	3	8	20	1	1	0	0
15	6	3	20	21	1	16	1	3	24	9	0	0	0
15	9	5	8	29	2	60	8	25	46	15	0	0	0
15	12	0	20	8	0	72	5	22	77	23	0	0	0
15	15	2	27	47	0	15	45	59	10	98	3	6	0

DISCUSSION

The Toxic Effectiveness of TETRAKOTE on the Test Insects

The experimental results indicated under conditions of laboratory tests, that rice weevils are easily controlled in the Colby sorghum grain. A mortality of 98 to 100 percent was obtained in Colby sorghum grain at all moisture levels treated with the five dosages. However, due to the high mortality rate in the control grain, it was believed that some unknown factor is involved in this mortality.

The mortality of rice weevils in treated Westland sorghum grain compares favorably with Colby of 11 and 13 percent moisture. Although a progressive increase in the mortality of rice weevils was noted as the dosages were increased, a complete kill was not obtained at the highest dosage in Westland of 15 percent moisture.

The results indicated that a higher dosage of protectant is needed to control the rice weevils in Martin sorghum grain when the moisture content is above 13 percent.

Saw-toothed grain beetles show considerable resistance to the protectant in all three varieties of sorghum grain tested. The highest mortality was obtained in Martin of 11 percent moisture treated at 3.5 gallons per 1000 bushels. In general, as the moisture content of the grain increased, the survival rate of saw-toothed grain beetles increased, and, as the dosage of the protectant increased, the mortality rate increased.

The results of the study indicated that lesser grain borers were successfully controlled in laboratory tests using the 3.5 gallons per 1000 bushel rate in all three varieties of sorghum grain.

The results obtained on granary weevils parallelled those on rice weevils when Colby and Westland grain were considered. The mortality of granary weevils, when exposed to Martin sorghum of 15 percent moisture treated at 3.5 gallons per 1000 bushels, was much higher than for rice weevils under the same conditions.

Flat grain beetles showed mortalities above 90 percent in all three varieties of sorghum at 11 and 13 percent moisture treated with 2.5 gallons per 1000 bushels. The results of tests using 15 percent grain were somewhat erratic. High dosages failed to give the desired mortality in any of the three varieties of sorghum of 15 percent moisture.

Little success was achieved in controlling confused flour beetles in the Colby and Westland sorghum grain of 13 and 15 percent moisture. The results obtained in the 11 percent tests using Colby and Westland were inconsistent. The irregular results obtained with Martin at the three moisture levels are indicative of unknown factors.

The Effects of TETRAKOTE on the Reproduction of the Test Insects

The reproduction of the test insects followed a definite pattern with a few exceptions which will be mentioned later.

Reproduction decreased as the dosage of the protectant was increased. An increase in the reproduction of the test insects resulted when the moisture content of the grain was increased.

Few insects developed and survived in the three varieties of sorghum at 11 percent moisture treated with protectant at 3.0 and 3.5 gallons per 1000 bushels.

Saw-toothed grain beetles developed in large numbers in Colby and Westland sorghum grains with a moisture content of 13 and 15 percent treated with protectant at 3.5 gallons per 1000 bushels. In the Martin of 11 and 13 percent moisture, saw-toothed grain beetles were controlled at dosage rate of 3.0 gallons per 1000 bushels.

The experimental results indicated that Martin sorghum grain is much more susceptible to attack by rice weevils than the other two varieties. The protectant failed to control rice weevils in Martin grain of 13 or 15 percent moisture. Progeny occurred in large numbers in Westland sorghum of 15 percent moisture at all disages, but the weevils were completely controlled in the 11 and 13 percent grain.

Reproduction of granary weevils was held to a minimum at all dosages and moisture levels tested in the Colby sorghum grain. In the Westland tests, reproduction of granary weevils was reduced in the 11 and 13 percent moisture grain, but large numbers developed in the 15 percent grain at all dosages. Dosages of 2.0 gallons per 1000 bushels or above held reproduction of granary weevils in check in the Martin grain of 11 percent moisture. The protectant failed to prevent reproduction of granary weevils in 13 percent grain at the high dosage. The 2.5 gallons per 1000 bushel treatment reduced the survival rate to a minimum in the 15 percent Martin grain.

The lower dosages of the protectant provided control of the lesser grain borer in the Colby and Westland sorghum grain at each moisture level. A dosage of 2.5 gallons per 1000 bushels was needed to prevent reproduction in Martin grain of 15 percent moisture. Large numbers of lesser grain borers developed in grain treated with 1.5 and 2.0 gallons per 1000 bushels. No lesser grain borers developed in Martin grain of 13 percent moisture treated with 2.0 gallons per 1000 bushels or more.

Lower dosages prevented reproduction of flat grain beetles in Colby grain of 11 and 15 percent moisture. A few insects developed in 15 percent grain treated at the 3.5 gallons per 1000 bushels rate. No flat grain beetles developed in Westland grain of 11 percent moisture. Two gallons per 1000 bushels held reproduction to a minimum in grain of 13 and 15 percent moisture. Reproduction of the flat grain beetles occurred in Martin of 13 and 15 percent moisture treated at the three lower dosages but was held at a low rate in the grain treated at the rate of 3.0 and 3.5 gallons per 1000 bushels.

Confused flour beetles failed to adhere to any set pattern of behavior. The only explanation that can be offered at this time is that these insects are living creatures. Resistance can vary within a species as well as in any higher taxonomic category.

SUMMARY AND CONCLUSIONS

Tests were conducted to determine the toxic effectiveness of TETRAKOTE, a liquid grain protectant, when applied at five dosages to three varieties of sorghum grain of 11, 13, and 15 percent moisture to six species of grain-infesting insects.

One hundred each of six species of insects, rice weevils, granary weevils, flat grain beetles, saw-toothed grain beetles, lesser grain borers, and confused flour beetles, were exposed to the test grain at dosages of 1.5, 2.0, 2.5, 3.0, and 3.5 gallons per 1000 bushels for 14 days. On the 14th day, the grain was screened and the numbers of alive and dead insects were determined and recorded. The test grain was held in the rearing room for an additional 35 days to develop progeny. On the 35th day, the grain was again screened and the numbersof alive adults were determined and recorded.

The conclusions based on data secured during this study are as follow:

1. A low dosage of protectant will control rice weevils in the Colby sorghum grain.

2. Saw-toothed grain beetles have considerable resistance to the liquid grain protectant.

3. A dosage of 3.5 gallons per 1000 bushels gave a 94 percent or above mortality to lesser grain borers in all three varieties of sorghum grain.

4. A low dosage of protectant successfully controlled granary weevils in Colby, but, in 15 percent moisture Westland

and Martin, some weevils survived.

5. Complete control of flat grain beetles was not obtained in the sorghum grains of 13 and 15 percent moisture.

6. No definite conclusions can be drawn on confused flour beetles until further work is completed.

7. When the moisture of the grain was increased, the survival rate and reproduction rate of the test insects increased.

8. With an increase in the dosage of the protectant, a decrease in the survival and reproduction of the test insects resulted.

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A LIQUID GRAIN PROTECTANT CONTAINING PYRETHRINS SYNERGIZED BY PIPERONYL BUTOXIDE AND ITS EFFECT UPON DEVELOPMENT OF CERTAIN INSECT POPULATIONS IN SORGHUM GRAINS

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TETRAKOTE, a liquid grain protectant, has recently been introduced into the grain industry for the protection of stored grain from insect infestation. Because of the low toxicity of the protectant to warm-blooded animals, it can be used on all cereal grains. The insecticidal ingredients in the protectant are piperonyl butoxide and pyrethrins in an ethylene tetrachloride carrier.

Since excellent results have been obtained in laboratory and field tests with the protectant applied to wheat at recommended dosage rate of two gallons per 1000 bushels, it was desired to know the toxicity of the protectant when applied at various dosage rates to sorghum grains with different kernel characteristics and moisture contents.

The dosage rates used in this study were 1.5, 2.0, 2.5, 3.0, and 3.5 gallons per 1000 bushels. Three varieties of sorghum: Colby, Westland, and Martin, were used. The species of insects used were the rice weevil, Sitophilus oryzae (L.); granary weevil, Sitophilus granarius (L.); flat grain beetles, Laemopholeus spp.; saw-toothed grain beetle, Oryzaephilus surinamenis (L.); lesser grain borer, Rhizopertha dominica (F.); and the confused flour beetle, Tribolium confusum Duv. Twenty-five unsexed adults of each test species were introduced into each test jar. The grain was adjusted to 11, 13, and 15 percent moisture. The treated and infested grain was held 14 days at 80° F. after which mortalities were determined. After test insects were removed from the grain, it was held for an additional period of 35 days to determine the extent of reproduction and survival of each species.

The mortalities of the rice and granary weevil were extremely high in the untreated jars of the Colby grain tests. As a result, a special test was conducted which indicated that rice and granary weevils are susceptible to some factor present in the grain that does not affect the other test insects appreciably. Colby grain of 11 percent moisture treated at the rate of 3.5 gallons per 1000 bushels gave relatively good results against all test insects. With a moisture increase, a decrease in mortality was noted.

In the Westland grain tests, 100 percent mortality of the rice weevil was obtained in 11 percent moisture grain treated at 2.5 gallons per 1000 bushels. At a moisture level of 15 percent and at the same dosage rate, 91 percent mortality was recorded. The saw-toothed grain beetle was not controlled in the Westland grain at any moisture or dosage level. In the grain of 11 and 15 percent moisture, a mortality of 90 percent or above was obtained on the lesser grain borer with a dosage rate of 3.0 gallons per 1000 bushels. The grain of 13 percent treated at 3.5 gallons per 1000 bushels gave a mortality of 100 percent for the grain borer. The granary weevil was controlled 100 percent in 11 percent treated at 3.5 gallons per 1000 bushels, but at 15 percent moisture, the mortalities were only 86 percent. As the moisture of the Westland grain was progressively increased, higher dosage rates were needed to obtain similar results with the flat grain beetle. At a moisture level of 11 percent, 2.0 gallons per 1000 bushels gave a complete kill, and, at 13 percent moisture, 2.5 gallons per 1000 bushels were needed to obtain the same results. Grain with 15 percent moisture treated at 3.5 gallons per 1000 bushels gave a 73 percent mortality rate for the grain beetles. The results obtained in the tests with the Westland grain and the confused flour beetle indicated the flour beetle quite resistant to the protectant at the dosage rates used.

The rice weevil was controlled 100 percent in the 11 percent Martin grain when treated at 3.5 gallons per 1000 bushels. At a moisture level of 15 percent, only 78 percent mortality occurred. Twenty-three percent of the saw-toothed grain beetles survived in the 15 percent grain treated at the rate of 3.5 gallons per 1000 bushels. When the Martin sorghum with moisture contents of 11, 13, and 15 percent were treated at 3.5 gallons per 1000 bushels, a mortality rate of 96 percent or above was recorded on the flat grain beetle. The granary weevil was controlled in the 11 percent grain by using the high dosage rate. A 4 percent survival was noted for the granary weevil in the 15 percent grain treated at 3.5 gallons per 1000 bushels. The tests indicated flat grain beetles can survive in Martin grain treated at 3.5 gallons per 1000 bushels providing the moisture content of the grain is 15 percent. The results obtained using the Martin sorghum grain and confused flour beetles were irregular. No definite pattern was established.

In the progeny tests, Colby grain with a moisture content of 11 percent which was treated at 3.5 gallons per 1000 bushels prevented the development and survival of all test insects with the exception of one rice weevil and two saw-toothed grain beetles. No lesser grain borers, flat grain beetles, or confused flour beetles developed in 11 percent Colby grain treated at 2.0 gallons per 1000 bushels and only two granary weevils developed. In the Colby grain of 13 percent moisture, treatment at 2.0 gallons per 1000 bushels was sufficient to limit the population increase of the rice weevil, flat grain beetle, lesser grain borer, and granary weevil to four insects or less per 1000 grams of grain. Irregular results were obtained on the progeny counts of the saw-toothed grain beetle and confused flour beetle.

No progeny developed and survived in the 11 percent, treated or untreated, Westland grain. The 15 percent grain treated at 3.5 gallons per 1000 bushels failed to prevent large numbers of rice weevils, granary weevils, or saw-toothed grain beetles from developing. The same grain treated at 1.5 gallons per 1000 bushels gave favorable results with lesser grain borers, flat grain beetles, and confused flour beetles.

Good results were obtained with Martin grain of 11 percent moisture content treated at 3.0 gallons per 1000 bushels. When 13 percent Martin grain was used, only fair results were obtained. The 11 percent Martin grain treated at 3.5 gallons per 1000 bushels gave favorable results on all test insects except the rice weevil.