START
The Biology and Control of the Sorghum Midge

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INTRODUCTION

The grain and sweet sorghums, together with the coarse hays made up of Johnson grass and Sudan grass, form a very considerable portion of the feed grown in the southern and western portions of the United States. Throughout much of these regions a large part of the seed occasionally fails to develop, resulting in a condition commonly known as blast or blight. A number of causes for this condition are known, such as adverse weather, pathological conditions, birds, and several insect pests. The most common and at the same time the most destructive agency is a minute fly known as the sorghum midge Contarinia sorghicola (Coq.).

If a head of any of the susceptible host plants is examined while in bloom, small, orange-colored midges may be found busily ovipositing in the spikelets. The drop of orange-colored liquid which exudes if the spikelet is pinched between the thumb and finger a few days later indicates a crushed larva.

1 Received for publication November 8, 1940.
2 The writer expresses his appreciation to Lee Benton, assistant scientific aid, Bureau of Entomology and Plant Quarantine, for his assistance in the numerous dissections and infestation counts necessary in this work, and to Charles H. Gable, formerly in charge of the Bureau of Entomology field laboratory at San Antonio, Tex., and W. A. Baker, assistant entomologist at the same laboratory from 1921 to 1929, for the use of unpublished notes, some of which have been incorporated in this bulletin.
3 Order Diptera, family Cecidomyiidae, subfamily Cecidomyiinae.
A careful examination of the infested spikelet within 2 weeks after the plant has bloomed will reveal a shriveled, darkened ovary and close beside it the minute, orange-colored larva or pupa of the sorghum midge. These are so small that in cases of severe infestation as many as a dozen may be found in a single spikelet.

HISTORY OF THE SORGHUM MIDGE IN AMERICA

The early history of the sorghum midge in America is not fully known. From the fact that it does not normally breed to any great extent in any known plant native to America, it may be considered as possibly of foreign origin. Another fact indicating its foreign origin and its comparatively recent introduction is that during the last half of the nineteenth century a sorghum of African origin, *Sorghum vulgare var. drummondi* (Nees) Hitchc., known commonly as chicken corn or wild corn, grew wild throughout much of the southern portion of the United States. In Louisiana and Mississippi, particularly, this was much used as hay. Since the closing years of the last century this sorghum has become less common and is now seldom found as a wild plant in the Southern States except in Louisiana and Mississippi. It also occurs locally in southern Indiana and northern Kentucky, where it is beyond the northern limit of serious midge infestation. The disappearance of this sorghum throughout the South has been attributed by Hansen (10) chiefly to the sorghum midge, which affected the heads and prevented the production of seed.

The earliest reference to the sorghum midge occurs in a report by Coquillett (2), in which he describes the appearance of several heads of sweet sorghum received from Dillburg and Montgomery, Ala., on October 2, 1895. These heads contained a large number of spikelets which failed to mature seed and which had apparently been destroyed by the larvae of a cecidomyiid. Only the empty pupal skins attached to the spikelets of the destroyed seed were found, however, and these gave no clue to the identity of the species. Nothing further was heard from this insect until September 26, 1898, when Coquillett received several heads of sorghum from College Station, Tex. This lot contained adults of the insect, which Coquillett determined as a new species and described under the name *Diplosis sorghicola*.

In 1908 C. R. Ball (1) showed that this insect was responsible for a great deal of the sterility in sorghums in Texas and Louisiana and gave a very brief description of its life history. He proposed the name “sorghum midge” for this insect.

The Yearbook of the Department of Agriculture for 1908 (12) mentions the sorghum midge by that name as having “destroyed the seed of sweet sorghum in the Gulf States.” This note also adds, “It has been reared from sorghum seed from North Carolina to central Texas and north to northern Kansas. So far it has not been observed west of the one hundredth meridian.”

In 1908 Piper (6) reported that a cecidomyiid, *Diplosis sorghicola*, had “destroyed the entire seed crop of sorghum south of a certain definite line in Texas.” He did not mention the location of this line but obtained evidence that the midge was responsible by bagging heads before they bloomed and obtaining a full set of seed on the bagged heads, while the seeds left exposed were destroyed.
Many other brief articles regarding this insect were published at about the same time, and as it was recognized that this loss of seed should be investigated, F. M. Webster, entomologist in charge of the investigations of cereal and forage insects for the Bureau of Entomology of the United States Department of Agriculture, arranged a cooperative project with Wilmon Newell, of the State Crop Pest Commission of Louisiana. R. C. Treherne was assigned to this work for the spring and summer of 1908 until he was relieved in July by W. Harper Dean. The results were published in 1910 and 1911 (4, 5).

Dean's work, although very well done, did not reveal a practical and effective method of control. Consequently, in 1920, Charles H. Gable and, in 1926, the writer were assigned to the work. A non-technical bulletin based on the work of Gable and his associates was published in 1927 (8).

Since Contarinia sorghicola was considered as of possible foreign origin, it became of interest to learn whence it might have come. Attention was called in correspondence by the late K. K. Kannan, of Mysore, India, to the fact that a very similar species, C. caudata Felt (7), is found in southern Asia. This midge lives on the sorghums and related grasses in that region, causes the same type of injury, has the same general appearance and life history, and is attacked by the same parasites as C. sorghicola. A number of specimens of C. caudata were therefore obtained from the Kolwah region in southern Baluchistan through the courtesy of Dr. Y. Ramchandra Rao and compared with specimens of C. sorghicola reared in this country.

E. P. Felt examined this material, and in a letter dated December 16, 1932, wrote:

I have not been able to find any clearly definable structural differences between the Texas and Baluchistan material. On the other hand, there are a number of general differences which make me unwilling to state positively that the two are identical.

He then called attention to some slight differences in size and color and stated further that—

The ovipositor appears distinctly longer than in the female of sorghicola and is commonly somewhat turned up above the horizontal rather than below as in sorghicola. The name caudata was bestowed in view of this very marked characteristic in the type material. * * * The genus Contarinia contains numerous very similar species, and for the present, I believe the interests of science will be best served by allowing caudata Felt to stand.

None of the differences mentioned by Felt are constant, however, and it has since been observed that when females of Contarinia sorghicola are killed by any common lethal agent the ovipositor is usually turned downward, but that when allowed to die naturally in hot weather the ovipositor is almost always more fully extended and turned upward. The Baluchistan material examined had been allowed to die in the envelope in which the infested spikelets were placed when collected.

Alan Steen examined this same material and under date of January 22, 1935, wrote:

I have compared 44 specimens of Contarinia caudata Felt, with 54 specimens of Contarinia sorghicola Coq. * * * and fail to see a single character that will separate the two. * * * The position of the ovipositor in most of the San Antonio specimens is somewhat different from that in caudata, but we have other specimens of sorghicola from Tennessee in which the ovipositor is held exactly as in our caudata specimens. There is nothing in the material at hand to lead me to consider Mr. Walter's opinion incorrect.
Although it is realized that the identity of the two species can be proved only by breeding, the opinions quoted, the known similarity in the life and habits, and the fact that there are no known native American hosts on which either breeds to any great extent offer strong evidence that *Contarinia caudata* Felt and *C. sorghiçola* Coq. are identical and that the original home of the species was possibly southern Asia, whence it was probably brought in some of the early importations of seeds.

**DISTRIBUTION OF THE SORGHUM MIDGE**

The sorghum midge has been recorded from Mexico, South America, the Dutch Antilles, Italy, Anglo-Egyptian Sudan, also from southern Asia if the species described by Felt as *Contarinia caudata* found on native Indian grasses should prove to be the same as *C. sorghiçola*. Adults were collected in the Sudan area for the first time in 1932, although the sterility of sorghum had been observed by the natives for several years (3). The sorghum midge now occurs throughout the southeastern quarter of the United States (fig. 1), having been reported in injurious numbers as far north as Charlottesville, Va., and Hastings, Nebr. It has not yet been found in injurious numbers very far west of the 100th meridian except along the Rio Grande from Presidio, Tex., to Las Cruces, N. Mex. The areas of most severe infestation occur in the more humid sections of the South and East. Injury is normally less severe in the drier, hotter, and more upland sections of northern Texas, Oklahoma, and Kansas. Y. Ramchandra Rao and K. K. Kannan, both of southern Asia, report in correspondence that the sorghums in the higher and drier portions of their countries are also less severely injured by *Contarinia caudata* than in the more humid sections at lower elevations.

**HOST PLANTS**

Experimental plantings of 48 varieties of grain sorghums and sweet sorghums and allied plants, broomcorn, Johnson grass, and Sudan grass have shown that all these grasses are attacked to nearly the same degree. The midge has not been found breeding to any great extent in the United States in any native grasses. Dean (5) records that he reared a single specimen from common foxtail grass (*Setaria*...
†utescens (Weigel) F. T. Hubb), a grass of European origin, and George G. Ainslie records only 4 specimens bred from purpletop (†riodia flava (L.) Smyth), a native grass, although he observed females ovipositing rather readily in its spikelets. L. C. Woodruff also records having had a few adults emerge from heads of T. flava. Thus it appears that although the sorghum midge will oviposit rather readily in this grass when other hosts are scarce, only a few individuals develop. Many other grasses have been tried as hosts under cage conditions, but the midge did not oviposit in them; and many grasses have been gathered in the field for observation, but emergence from them has not been obtained.

INJURY TO SORGHUM

The injury caused by this insect results from the feeding by the larva on the developing seed. An infested seed is seldom more than a discolored, shrunken hull of one-fifth to one-third normal size. This stunted growth is not sufficient to expand the glumes, hence

the spikelet matures with the appearance of sterility, and its size and shape differ but slightly at time of maturity from what they were at time of blooming (fig. 2, B). It is often difficult, if not impossible, to determine from outside appearance whether the spikelet is infested or whether it is sterile because of lack of fertilization or some other cause.

1 Unpublished notes.
OTHER CAUSES OF STERILITY

Several agencies other than the midge may cause injury to spikelets on a sorghum head. Sorghums normally produce a sterile pedicellate spikelet with each fertile or sessile spikelet. Some varieties retain these sterile spikelets to maturity. Although midge larvae often develop in these sterile spikelets, this condition should not be confused with midge injury to the fertile spikelets. Birds frequently pick the seed from the spikelet, but their work can be readily differentiated from midge injury by the curling of the glumes and the ragged appearance of the head (fig. 2, C). The larvae of the sorghum webworm (Celama sorghiella Riley) often eat out the kernels, causing a condition that resembles midge work. On careful examination, however, webworm injury can be distinguished by the fact that the edges of the glumes are usually somewhat gnawed to give the larvae access to the kernel. Occasionally a head fails to emerge completely from the "boot," thus causing the bottom of the head to show many sterile spikelets due to incomplete fertilization.

There is another factor not so well known or understood. For many years farmers in the more humid sections have noticed a blighting of the heads blooming during a period of excessive rain, and at one time considered all blighting as due to the rains. An example found in 1929 will serve to illustrate this. The first crop in a field of several hundred acres of hegari near Taft, Tex., was cut by blocks starting at one end of the field and continuing to the other end. The entire harvest required a period of about 3 weeks. On the blocks harvested earliest the second crop came into bloom during a period when about 30 inches of rain fell in a few weeks. These blocks produced no grain whatever. Later blocks, blooming as the precipitation slackened, showed increasingly better crops of grain, until the last, which bloomed after the rains, bore an excellent crop.

Some of the blighted heads were shown to C. S. Scofield of the Bureau of Plant Industry, and to George T. Radcliffe, who was at that time also with that Bureau. Both expressed doubts that the injury could be due directly to the rain and thought that a fungus might have developed on the heads during the wet weather and that this prevented the development of the seed. Examination of the heads under a lens showed that much fungus had been present. Other similar cases have been observed elsewhere along the Gulf coast. Ordinarily, dissection of the spikelets is necessary to differentiate this type of injury from that produced by the sorghum midge.

LIFE HISTORY

THE EGG

DESCRIPTION

The egg (fig. 3) is colorless, very delicate, cylindrical, and somewhat smaller at one end, to which is attached a slender, tapering appendage. In the freshly deposited egg this appendage is viscous and is approximately the length of the egg proper, but it soon dries and shrivels to less than half its original size. This limp, viscous
appendage precedes the egg when it is deposited and while fresh lies in a straight line beyond it. Its use is not definitely known but it is probably to attach the egg to the glumes and pull it from the ovipositor. The average measurements of 14 freshly deposited eggs show the length of the egg proper to be 0.296 mm. and the width 0.061 mm.

Within the ovary the eggs are packed tightly in no apparent order other than that all the appendages are directed toward the ovipositor. In a freshly emerged female the eggs nearest the oviducts are fully developed, but a few are found at the back that are only partly developed. These immature eggs also have the appendage. As they develop they lengthen and lie partly beside the others. Undeveloped eggs are not found in females 24 hours old.

**Figure 3.**—Eggs of the sorghum midge, X 200.

**NUMBER OF EGGS PER FEMALE**

The number of eggs per female varies greatly. Dissection of 17 females from cocooned larvae that had not been given opportunity to oviposit showed an average of 60.54 eggs per female with a range of from 28 to 124. Dissection of 20 females during the summer gave an average of 90 with a range of from 70 to 121. The full quota of eggs is seldom deposited before the death of the female.

**DURATION OF THE EGG STAGE**

The length of time required for the egg to hatch varies according to the temperature and possibly other factors, but may range from 42 to 60 hours or more. Two methods were used to determine the duration of the egg stage. In one, the egg was dissected from the spikelet, placed in a small paraffin cage with a drop of moisture to prevent it from drying, and covered with a microscope cover glass. Most of the eggs treated in this way hatched, but it was felt that the conditions were too unnatural. Another method was to allow a large number of females to oviposit for 1 hour in spikelets on a head that had been bagged to prevent previous oviposition. At the end of the hour the females were removed and the head again bagged to prevent further oviposition. As soon as it was thought possible for the eggs to begin to hatch, spikelets from the head were brought to the laboratory for dissection, and this was continued until the hatch was complete. The average incubation period thus found is given in table 1. It corresponded very closely to the time found under cage conditions.
TABLE 1.—Incubation period of eggs of Contarinia sorgicola at different temperatures

<table>
<thead>
<tr>
<th>Eggs (number)</th>
<th>Average duration of egg stage (hours)</th>
<th>Average temperature by 2-hour intervals (°F)</th>
<th>Eggs (number)</th>
<th>Average duration of egg stage (hours)</th>
<th>Average temperature by 2-hour intervals (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>123</td>
<td>85.00</td>
<td>5</td>
<td>23</td>
<td>85.00</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>85.00</td>
<td>13</td>
<td>84.00</td>
<td>85.00</td>
</tr>
<tr>
<td>13</td>
<td>48</td>
<td>85.00</td>
<td>23</td>
<td>76.20</td>
<td>85.00</td>
</tr>
</tbody>
</table>

The newly hatched larva closely resembles the egg in shape and appearance and is nearly colorless. It soon crawls down toward the base of the spikelet and normally feeds on the developing ovary at that point. As it feeds it gradually becomes a pale pink changing to deeper pink, then orange, and when full grown is a dark orange, or sometimes reddish orange. The larva (fig. 4) is slightly flattened and tapers to a point at the head. The posterior end tapers somewhat less to an abrupt, blunt end. The head and fore part of the body are retractile.

The full-grown larva just before pupation is 0.83 mm. wide and 2.09 mm. long with the head extended and 1.5 mm. with the head retracted. At this time the larva ceases to feed and remains quiet for a few hours, during which period there is a decided clearing of the orange color near the head. After this brief rest the larva reverses itself in the depression in which it lies and is then found with its head toward the apex of the spikelet and with its back to the ovary. This apparently is the only time it moves after it begins to feed. It pupates in that position and remains there until ready to emerge as the adult.

The time spent as a larva during the summer season is about 9 to 11 days, as shown in table 2.

TABLE 2.—Duration of the larval stage of individuals of Contarinia sorgicola that complete development during the summer

<table>
<thead>
<tr>
<th>Period</th>
<th>Larvae observed</th>
<th>Duration of stage</th>
<th>Mean temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Days</td>
<td>°F</td>
</tr>
<tr>
<td>June 26—July 5</td>
<td>120</td>
<td>12</td>
<td>82.2</td>
</tr>
<tr>
<td>June 26—July 9</td>
<td>320</td>
<td>16</td>
<td>83.7</td>
</tr>
<tr>
<td>July 11—July 25</td>
<td>149</td>
<td>95</td>
<td>83.5</td>
</tr>
<tr>
<td>July 18—July 28</td>
<td>88</td>
<td>10</td>
<td>84.0</td>
</tr>
<tr>
<td>Sept. 16—Sept. 27</td>
<td>2</td>
<td>114</td>
<td>82.2</td>
</tr>
</tbody>
</table>
METHOD OF FEEDING

Until fully-fed the larva is usually found lying lengthwise with, and directly against, the developing ovary with its head toward the base of the ovary. In one instance 60 larvae were found directly against the ovary, 8 between the palel and inner glume, and 3 between the inner and outer glumes. In another instance 44 larvae were against the ovary and 15 between the inner and outer glumes. In some varieties of grain sorghum, particularly in hegari, it is not at all uncommon to find fully developed larvae and pupae in the sterile spikelets where they have of necessity drawn their nourishment from the glumes (fig. 5).

Early writers mention that the larva absorbs its nourishment through the body wall. Dissections, however, show that the larva has well-developed mouth parts and digestive tract. The only argument found in favor of the absorption theory is that the kernel is depressed where the larva lies in contact with it, but this can be explained by the fact that the plant juices are drawn off at the base of the depression, so the kernel would have less chance to fill at that point. The mechanical pressure of the larva would also have some tendency to cause a depression.

METHODS OF PUPATION

The majority of the larvae form naked pupae on completion of growth, but a varying proportion of them, depending on conditions, form cocoons at the places where they have been feeding and enter a resting period which may last for as much as 2 or 3 years. This cocooned form seems to be an adaptation for carrying the species over periods of adversity. It is the only stage capable of living through the winter in the United States. The naked larvae and pupae are killed by cold weather, but the cocooned larvae seem to be little affected by short exposures to temperatures as low as 10° F. Extended exposure to lower temperatures, however, kills many of these also.

The cocoon (fig. 6) varies considerably in size, depending on the size and condition of the larva at the time it is formed. It is somewhat elliptical, slightly flattened in the middle and tapering at each end. It is rather thin in structure and is translucent at first, but as it ages it becomes more opaque and takes on a dull ashy-gray color which changes finally to a light brown. The method by which the cocoon is formed has not been observed. The fresh cocoon consists
of a single chitinous layer to which the hairlike bristles of the glumes adhere. It is probably a puparium, although it does not show the larval form or characters. It is later lined with a closely spun layer of fine silk. Contrary to the description given by Dean (3), the cocooned larva is full-grown but is reduced somewhat in size with the making of the cocoon and by later body metabolism. It is more flattened than the naked larva, and the head is withdrawn more into the body. In no case has the writer observed it surrounded by protoplasmic fluid as described by Dean. In some cases the larva reverses its position as does the naked larva before pupating, but more often it is found with the head downward as in the feeding position. The sizes of larvae and cocoons are given in table 3.

The reasons certain larvae form cocoons and others do not are not well known. Often a few larvae from each generation are found to enter that prolonged resting stage. The cocoons are most commonly formed during the hot dry weather of July and early August, and again late in the fall, when many individuals form cocoons in which to pass the winter. The percentage of the larvae forming cocoons during the summer seems to be related to the extent of the heat and drought. It seems probable that there is a range of temperature within which the larva normally pupates and completes its life cycle, and that temperatures either above or below this optimum will cause much cocooning. More cocoons may be formed during the summer than late in the fall. This may be due in part to sudden fall freezes that kill the late-maturing larvae.

At intervals throughout the seasons of 1921, 1922, and 1924, W. A. Baker tagged a number of heads of sorghum that were just beginning to bloom. These heads were left to normal infestation. He later dissected 500 infested spikelets picked at random from each series to determine the percentage of larvae forming cocoons at each date. His results, as found in his unpublished notes, are summarized in table 4.
THE BIOLOGY AND CONTROL OF THE SORGHUM MIDGE

TABLE 4.—Relationship between temperature at the time of maturity of larvae of Contarinia sorghicola and their tendency to form cocoons, 1921, 1922, and 1924

<table>
<thead>
<tr>
<th>Year</th>
<th>Date heads began to bloom</th>
<th>Larvae forming cocoons</th>
<th>Average temperature during cocooning period</th>
<th>Date heads began to bloom</th>
<th>Larvae forming cocoons</th>
<th>Average temperature during cocooning period</th>
<th>Date heads began to bloom</th>
<th>Larvae forming cocoons</th>
<th>Average temperature during cocooning period</th>
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<tbody>
<tr>
<td>1921</td>
<td>July 7</td>
<td>15.2</td>
<td>85.7</td>
<td>June 11</td>
<td>22.2</td>
<td>83.2</td>
<td>June 4</td>
<td>0.4</td>
<td>76.5</td>
</tr>
<tr>
<td></td>
<td>July 23</td>
<td>5.2</td>
<td>84.7</td>
<td>July 11</td>
<td>32.6</td>
<td>86.8</td>
<td>July 14</td>
<td>2.3</td>
<td>81.0</td>
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<td></td>
<td>Aug. 13</td>
<td>1.0</td>
<td>83.1</td>
<td>Aug. 14</td>
<td>1.0</td>
<td>86.2</td>
<td>Aug. 19</td>
<td>4.4</td>
<td>85.3</td>
</tr>
<tr>
<td></td>
<td>Sept. 13</td>
<td>7.2</td>
<td>77.2</td>
<td>Sept. 11</td>
<td>6.0</td>
<td>75.8</td>
<td>Sept. 22</td>
<td>4.4</td>
<td>79.5</td>
</tr>
<tr>
<td></td>
<td>Oct. 11</td>
<td>71.0</td>
<td>67.3</td>
<td>Oct. 16</td>
<td>20.4</td>
<td>70.0</td>
<td>Oct. 8</td>
<td>1.6</td>
<td>63.7</td>
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<td></td>
<td>Oct. 23</td>
<td>62.3</td>
<td>66.8</td>
<td></td>
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</table>

1 Humidity was rather high for several days at the time the larvae matured, but no rain was recorded.

A sorghum head is normally in bloom over a period of about 7 days, therefore it is assumed that oviposition on these heads occurred over approximately a 7-day period and that larvae were maturing over a like period. The approximate 7-day period at which most of the larvae matured on each series of heads was determined from additional notes by W. A. Baker, and the average temperatures for these periods were taken from daily thermograph records kept at the laboratory. The averages of the temperatures taken at 2-hour intervals during these periods are shown in table 4.

From this work it appears that very few larvae form cocoons when the average temperature is approximately 75° F., but that the percentage of larvae forming cocoons increases directly as the average temperature goes either much above or below this point. Rainfall at the time the larvae mature during the summer seems to decrease the numbers forming cocoons, but as rainfall at that time is usually accompanied by cooler weather the extent of its effect is somewhat obscured. No rain fell at or near the times of cocoon formation during the seasons of 1921 or 1922. On the other hand, 1924 was rainy throughout the season.

Cocooned larvae normally remain unchanged until the following spring, when pupation and emergence take place. If conditions are not favorable for emergence at that time, the larvae may remain dormant until the next year. In screen cages placed on the ground a few have even held over until the third spring. A prolonged warm and wet period late in the summer may bring out many of the cocooned individuals, particularly among those that formed cocoons during the early part of the season.

THE PUPA

When the larva completes its development it turns within the depression formed in the seed by its feeding so that the head is toward the apex and the dorsum toward the seed, and in this position it pupates. The pupa at first is uniformly dark orange but after a few hours the head, antennae, legs, and thorax darken until they become black. The abdomen retains the orange color.

The duration of the pupal period, of pupae derived from naked larvae, is from 2 to 6 days, with an average of between 3 and 4 days.
Pupae from the cocooned larvae may live as such for a slightly longer period early in the spring. In no case, however, is the pupa capable of withstanding long periods of either drought or cold weather, hence the pupal form is not capable of carrying the species through periods of adversity.

**The Adult Emergence**

When ready to emerge, the pupa works its way toward the apex of the spikelet until about three-fourths of the pupal length protrudes from the tip. The pupal skin then separates from the adult within and splits along the dorsum of the thorax to allow the emergence of the adult. Emergence is accomplished by an expansion and contraction of the abdomen resembling the crawling of a larva and is aided at the last by pulling with the first pair of legs. The pupal skin remains protruding from the tip of the spikelet. When free and undisturbed the adult usually remains quiet for at least 15 minutes, or until the wings have expanded and hardened. When disturbed, however, adults sometimes attempt to fly within 2 minutes after emergence. Adult emergence may occur at any time of the day but normally begins soon after midnight and is practically complete for the day by noon. Emergence is heaviest at about sunrise or soon after. Over 60 percent of the total emergence takes place between the hours of 5 and 8 a.m.

**EFFECT OF WEATHER ON EMERGENCE FROM COCOONS**

During the several years that the midge was under observation at San Antonio, Texas, a relationship between weather conditions and emergence of the adults from overwintering cocoons was evident. In some years emergence began late in March or early in April, but in other years there was no emergence until sometime in May. Several attempts were made to find a correlation between peaks of emergence and the immediately preceding weather conditions, with particular emphasis on rainfall. The usual occurrence of at least a light rainfall every 10 days to 2 weeks, however, obscured this relationship between rainfall and emergence. The extreme peaks of emergence usually, but not always, occurred at a time when the weather was warm and humid and within a few days after a rain. Lesser peaks often occurred while the weather was dry.

The spring and summer of 1933 were very dry, with few rains and only two periods when the midge adults emerged in numbers, and so these seasons offered better conditions for a correlation of emergence with climatic conditions. When the emergence for that season was charted it was seen that each of the peaks occurred a considerable time after a rain. The first occurred 13 days after a rain on May 25, and the second occurred 12 days after a rain on June 12. The emergence records for other years were then charted, tracing back to previous rainfall. It was then found that emergence occurred in from 10 to 22 days after a rain, depending on the mean average temperature for the period (table 5).
### Table 5.—Number of days at different average temperatures between occurrence of rainfall and emergence of adults of Contarinia sorghicola from cocoons

<table>
<thead>
<tr>
<th>Year</th>
<th>10 days</th>
<th>11 days</th>
<th>12 days</th>
<th>13 days</th>
<th>14 days</th>
<th>15 days</th>
<th>16 days</th>
<th>17 days</th>
<th>18 days</th>
<th>19 days</th>
<th>20 days</th>
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<td>1921</td>
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<td>72.9</td>
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<td>75.1</td>
<td>75.1</td>
<td>75.1</td>
<td>75.1</td>
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<td>75.1</td>
<td>75.1</td>
<td>75.1</td>
</tr>
</tbody>
</table>

With a mean temperature of above 80°F, a peak of emergence occurred in 10 to 11 days after a rain, while lower temperatures were followed by emergence in a correspondingly longer time. It was also shown that a sudden and decided drop in temperature, such as occasionally occurs in Texas, coming at the time emergence should normally take place delayed the peak for a day, whereas rain followed by warm weather sometimes hastened it by as much. The first emergence for the season occasionally required a slightly longer than the normal period, particularly when the early part of the season was very dry, as was the case in 1933. This would indicate that the earlier rains may give some stimulation although not enough to cause emergence.

The emergence considered in this study was that from the regular spring emergence cages. These were of a type that had been found best suited for work with the sorghum midge. They consisted of a framework 30 inches square and 16 inches deep enclosed with black cotton cambric cloth. The bottoms were slatted so that the sorghum heads were held about 4 inches off the ground. The cages were set in a light shade so as to be protected from the direct rays of the sun. The temperatures given in the table were the averages of the temperatures at 2-hour intervals as recorded on a thermograph in a standard weather shelter about 15 feet away.

Although less evidence is at hand, observations indicate that the same relationship between rainfall and emergence exists in the case of the cocooned larvae in the field during the summer as with the overwintered cocooned larvae. In this connection it may be noted that when a summer drought is broken by rain, the midges emerge in about the same length of time that it takes the older host plants to develop lateral shoots and flowers—a remarkable adaptation of the insect to its host.
DESCRIPTION OF THE ADULT

The adult of the sorghum midge (fig. 7) is a minute, orange-colored two-winged insect, the male measuring approximately 1.3 mm. in length and the female 1.6. The sexes are readily differentiated by the more robust appearance of the female, her more deliberate movements as compared with the quick, nervous actions of the male, and by the fact that the antennae of the male are nearly as long as the body whereas those of the female are less than half the length of the body. A summary of the size of 20 individuals of each sex is shown in Table 6.

![Figure 7: Adult female of the sorghum midge with ovipositor extended, X 20.](image)

**Table 6. Summary of the measurements of 20 individuals of each sex of Contarinia sorghiicola, San Antonio, Tex.**

<table>
<thead>
<tr>
<th>Measurement made</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (Millimeters)</td>
<td>Maximum (Millimeters)</td>
</tr>
<tr>
<td>Body length</td>
<td>1.33</td>
<td>1.57</td>
</tr>
<tr>
<td>Body width</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Wing length</td>
<td>0.40</td>
<td>0.57</td>
</tr>
<tr>
<td>Wing width</td>
<td>0.44</td>
<td>0.61</td>
</tr>
<tr>
<td>Antenna length</td>
<td>1.20</td>
<td>1.39</td>
</tr>
<tr>
<td>Ovipositor length</td>
<td>1.53</td>
<td>1.83</td>
</tr>
</tbody>
</table>

MATING

Mating normally takes place soon after the emergence of the female and before she leaves the spikelet from which she emerged. Instances have been noted of mating immediately after emergence of the female and before her wings were expanded. If given time to develop strength to defend herself, she will not ordinarily permit mating in less than 10 or 15 minutes. The female does not ordinarily mate more than once.

LENGTH OF ADULT LIFE

It is doubtful whether a female that has oviposited freely will live more than 1 day in the open during the hot, dry summer. Females seldom live more than 24 hours under these conditions in cages, and are scarcely to be found in the field after 4 or 5 p.m. The males are
seldom found in the field after noon. Both sexes may live 4 or 5 days under cage conditions if given plenty of water or dilute honey.

The adults have not been observed feeding on honeydew from aphids. Moisture and other suitable food are very scarce in the fields, and it is not probable that many find enough to keep them alive very long. The females are occasionally observed apparently attempting to feed at the apex of a freshly opened spikelet and at points of injury to the plant where some moisture might be available. Such occasions are rare, however, and the females seem much more interested in ovipositing than in feeding.

GENERATIONS PER YEAR

The possible number of generations per year varies with the season. Occasionally at San Antonio, Tex., emergence begins late in March or early in April, and sometimes a few heads of Johnson grass may be found at that time. Ordinarily, however, the first adults emerge about the middle of April. Activity in the field may be halted in November or not until sometime in December by the death of the host plants due to killing frosts. A generation occurs every 13 to 16 days with an average of about 14 days during the summer. Usually 13 generations occur during the year.

RATIO OF MALES TO FEMALES

A tabulation of the adults emerging in cages from overwintered larvae over a period of 12 years shows 44.7 percent of males and 55.3 percent of females. Emergence from naked summer pupae gave 35.6 percent of males and 64.4 percent of females.

OVIPOSITION

As soon as the female becomes strong enough she begins to search for suitable spikelets in which to oviposit. When one is found she takes a position at or near its tip, often partly supporting herself by holding to the spikelet above. The tip of the abdomen is then depressed and the ovipositor is extended and retracted with a nervous, pistonlike movement feeling for an opening in the spikelet. She may remain in this position for a half minute or more attempting to find a suitable opening before succeeding or desisting to try elsewhere. As soon as a suitable point is found, the ovipositor is extended its full length, and the female remains motionless except for a certain amount of straining for about 2 seconds while the egg is being forced the length of the ovipositor. When the egg has been placed, the female immediately leaves that spikelet to search for another. Very seldom will she place 2 eggs in the same spikelet in succession although she may return to deposit another later. She is often followed in rapid succession by other females ovipositing in this spikelet; so it is not unusual to find as many as 10 to 15 or more eggs in a single spikelet. As many as 13 larvae have been found to mature in a spikelet.

The time required for a single oviposition may be from half a minute to ten minutes or more. In one instance 3 females deposited 168 eggs in 4 hours, making an average of approximately 4 minutes for
each egg. At another time 50 eggs were deposited by 3 females with an average interval for each of only 2 minutes and 44 seconds.

When the weather is cool, oviposition takes place slowly, but the rate is increased as the temperature increases, until the height of oviposition is reached shortly before noon. By 4 p.m. oviposition has practically ceased for the day. A female that has oviposited freely during this time is so exhausted that she seldom lives until the next day.

The egg is usually placed near the tip of the spikelet just under the outer glume and attached to the fine hair found there. The next most common place of attachment is under the inner glume. Dissection of several hundred spikelets showed eggs to be distributed as follows:

<table>
<thead>
<tr>
<th>Location of egg:</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under the outer glume</td>
<td>60.24</td>
</tr>
<tr>
<td>Under the inner glume</td>
<td>20.49</td>
</tr>
<tr>
<td>On palea</td>
<td>8.43</td>
</tr>
<tr>
<td>On stamen</td>
<td>8.43</td>
</tr>
<tr>
<td>On outside of spikelet</td>
<td>2.41</td>
</tr>
</tbody>
</table>

Oviposition takes place most commonly while the spikelet is in bloom, but it may occur at any time while the glumes remain flexible, from the time they begin to open until they have closed and become hard, a period of from 2 to 4 days. About 7 days are usually required from the time of the first bloom until blooming is completed on a given head. This gives a period of about 10 days during which oviposition may occur on a single head, although nearly all of it occurs while the spikelets are in bloom. When blooms are scarce oviposition will sometimes begin as soon as the spikelets appear and continue after the glumes have hardened, so it is sometimes possible to find all stages from egg to fully developed pupae in the same spikelet.

**METHODS OF DISTRIBUTION**

**Transportation in Seed and Hay**

As stated previously, the only form in which the sorghum midge lives for any great length of time is that of the dormant larva encased in a cocoon. In this stage, however, it has been observed to survive as long as 3 years and then produce normal adults. This insect can thus be carried long distances as the dormant larva in seed or hay of its host plants and probably has been distributed around the world in this way. When the sorghum is threshed many infested spikelets are carried over with the seed, and they or the cocoons from them may be shipped into uninfested territory in sorghum seed. Obviously broomcorn or hay made from sorghum, Johnson grass, or Sudan grass may also serve as media for the accidental transportation of the midge in commerce.

**Dispersal by Flight**

Because of the frailty of this insect and its slow flight and because at best its active adult life is of only a few hours duration, its dispersal by flight could be for only short distances.
CHARACTER AND DIRECTION OF FLIGHT

Flight screens, covered with a thin coating of a commercial tree-banding material, were placed on the four sides of seven different fields just coming into bloom to determine the amount and direction of flight of midges to them. These screens were 4 feet square and placed so that the bottoms were 2½ feet from the ground. The prevailing wind in all cases was from the south or southeast. Screens at five of the fields were placed 4 feet from the edge of the planting. This appeared to be too close, and many of the midges caught on the side next to the field may have been caught by accident while flying about the host plants. Screens at the other two fields were placed 100 feet outside the field and possibly better showed the true character of flight. Daily readings of the catch on these screens showed that while the fields were in bloom the flight was nearly always toward the field and with the wind. After blooming had ceased the flight was outward, but again with the wind. Very little tendency of the midges to leave the field was shown as long as there was favorable opportunity for oviposition. Of the individuals caught on these screens by far the greater number were females, indicating that the females are much more inclined to migrate than are the males.

SOURCES OF INFESTATION

Precocious Blooms

A number of observations have been made which show conclusively that although there may be a migration of midge adults from outside sources into a field, the greatest danger to the crop lies in the infestation built up within the field itself. Since infestation usually takes place only in blooming heads, a few heads of sorghum or Johnson grass blooming in a field ahead of the main crop give an opportunity for the females to oviposit on these, with the result that the next generation, emerging 2 weeks later, may be the cause of an infestation that will practically destroy any heads blooming at that time. The elimination of these early blooming heads, either by roguing or by the use of a pure strain of an evenly blooming variety, removes this source of midges that would infest the main crop. These measures enable the main crop to reach full bloom in from 6 to 8 days after the first bloom and to be past blooming except for a few late plants in from 12 to 14 days, or before a generation of midges has had time to mature within the field. It is obvious, then, that any heads blooming much in advance of the main crop should be removed for its protection.

Baker made careful infestation counts on 100 successive heads in a row at 3 different places in a field on each of 6 widely separated farms in 1924. He found approximately 20 percent of the spikelets that bloomed during the first 12 days to be infested, but that the infestation jumped to nearly 100 percent as soon as emergence began in the field. The proportion of the crop lost in the various fields was determined very largely by the proportion blooming after emergence in that field began.
Another source of infestation is found in the practice sometimes followed of planting an early and a late variety side by side, or successive plantings of the same variety in the same or adjoining fields in hopes that at least one of the plantings will experience favorable weather. When this is done the early crop furnishes a source of infestation for those maturing later. One example of this as found by Baker showed 12 percent loss to the early hegari and 67 and 70 percent, respectively, to two adjoining fields of feterita that were beginning to bloom just as the hegari was completing its bloom.

PARASITES AND PREDATORS

Parasites

Three hymenopterous parasites of the sorghum midge have been recorded so far. Two of these, *Aprostocetus diplosidis* Cwld., and *Tetrastichus* sp., were mentioned by Dean (5, pp. 55-56) as being of considerable importance in the control of the midge. The third species, *Eupelmus popa* Gir., which is now by far the most important was not mentioned by Dean nor was it recorded from this country until collected by Gable in 1920, as recorded by Gahan (9).

Dean (5) records *Aprostocetus diplosidis* as being the predominant parasite and states that it is “very aggressive and parasitizes the midge very actively.” He also states that “late in summer emergence of these parasites and midges from infested heads is approximately in the proportion of 1 of the former to 1 of the latter,” thus indicating that at the time his observations were made they were very abundant. In notes made during the season of 1920 Gable indicates *A. diplosidis* to be one of the less common species. Since the writer took over this work in 1926 no specimen of *A. diplosidis* has been seen, although diligent search for them has been made in the fields and many emergence cages have been installed each year containing infested heads from many parts of Texas and Louisiana, and some from as far east as Florida. Considerable material reared by others has been examined without a single specimen being found. Such complete disappearance of so prominent a parasite is hard to explain.

Dean (5) states that the species of *Tetrastichus* he found “is known to be both primary and secondary, but is more likely to be primary in its relation to the midge.” This species has also ceased to be important in the control of the midge. The season of 1929 is the only one since 1926 during which it has been observed in the fields of Texas, and it was present in extremely limited numbers that year. Dean states that it has also been reared from *Setaria lutescens* infested by another species of midge. Its disappearance from sorghum is also mysterious.

By far the most abundant and effective parasite during the years 1926 to 1934 was a small chalcidoid, *Eupelmus popa* (fig. 8). Dean did not record this parasite when he did his work in 1908-9. Gable records it in his manuscript notes as being, in 1920, “as abundant as the other two combined.” With the exception of the one season, 1929, it is the only parasite seen since 1926, the other two species apparently having almost completely disappeared.
*Eupelmus popa* was described by Girault in 1917 from specimens received from the Dutch Antilles. Since its first reported appearance in the United States in 1920 it has been recorded from Cuba and from several places in India, where it has been reared from the midge *Contarinia caudata* on sorghums and native grasses. This species also hibernates within the injured spikelet as a larva and is capable of remaining in that form for a year or more if conditions for emergence are not favorable. Specimens have emerged after as long as 3 years in cages on the ground. It is possible that it has been distributed through the sorghum-producing regions with the seed and other products.

C. R. Ball, formerly of the Bureau of Plant Industry, United States Department of Agriculture, suggested to the writer that it may have been introduced into the United States with some sorghum seed imported by him from India in 1909 and planted that year at Chillicothe, Tex. Several varieties of this seed were sent from Chillicothe to San Antonio for planting the following year, and thus the parasite may have been brought to San Antonio just after Dean completed his work there.

The life history of *Eupelmus popa*, as shown by Woodruff (13), follows rather closely that of the sorghum midge except that the adults may live for a week or more. It passes the winter as a larva and usually begins to emerge from hibernation in large numbers 2 or 3 weeks later than the sorghum midge, thus permitting the midge to get a

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**Figure 8.**—*Eupelmus popa*, a parasite of the sorghum midge; adult female, X33.
start in the spring. When the emergence of *E. papa* in cages is charted, as was done for the sorghum midge, it is seen that development is stimulated in the same way as for the midge, but that emergence does not occur until about 5 to 8 days later. This gives ample opportunity for the midge larvae to become well developed before being parasitized.

The adult female parasite crawls about over the spikelets, examining them with her antennae. When a suitable infected spikelet is found, she crawls to its tip and thrusts her long ovipositor down between the glumes and deposits an egg in much the same position as the egg of the midge was deposited earlier. These eggs hatch in from 24 to 30 hours, and the young larvae crawl down to find the midge larvae feeding at the bases of the spikelets. One full-grown midge larva is usually enough food to enable an *Eupelmus* larva to complete development. Two or more small larvae are often consumed, however, when available. Occasionally, when other larvae are not available and more food is needed, the *Eupelmus* will complete its development by feeding on the injured seed itself after it has consumed the midge larvae. There is no record, however, of the *Eupelmus* larva feeding on the seed until after it has first fed on the midge. It therefore feeds only on seeds that have already been injured and so cannot at present be considered a potential menace to the crop. From about 14 to 16 days are required to complete the life cycle. The parasite is abundant enough by the middle of summer to be very effective in the control of the midge. It may also become dormant at almost any time of the year, as does the midge, and remain so for a year or more until conditions become favorable for emergence.

**Predaceous Enemies**

Owing to its concealment for most of its life within the spikelets of the host plant, the sorghum midge is almost entirely free from predaceous enemies. When the adult emerges from the spikelet, however, it does not fare so well. A complete list of its enemies would probably include nearly all the predators found within the sorghum field. Several species of ants may be found on the sorghum head ready to seize it and carry it away. Chief among these ants are the Argentine ant (*Iridomyrmex humilis* Mayry) and the closely related *Iridomyrmex analis* (André). A small, odorous ant, *Pheidole* sp., is also frequently found on the sorghum head in great numbers. The fire ant (*Solenopsis geminata* (F.)) and several other species also often capture many of the adults. Most of those destroyed by ants are captured just as they emerge from the spikelet.

The spiders *Metepeira labyrinthica* (Hentz), *Epeira pratenis* Hentz, a Thomisid, and a species of *Dictyna* have been observed to capture as many as 50 adults per day in their webs, while *Philippus audax* (Hentz), *P. mystaceus* (Hentz), 3 attid species, and several other unidentified jumping spiders have been observed to capture the adults while they were ovipositing in the spikelets.

The robber fly *Atomosia puelle* Wied. was observed by Gabie capturing the adults. Dean (5) records another dipteran (*Psilopodinae*) *Psilopus flamipes* (Aldrich), of the Dolichopodidae, as feeding on them also.

*Geocoris punctipes* (Say), *Zeltus socinus* Uhler, *Orius insidiosus* (Say), and several other small Hemiptera have been observed feeding on the
adults. *O. insidiosus* was often found in the hibernation cages in the spring as well as on the sorghum heads during the summer, feeding on the emerging adults.

A damselfly, *Argia* sp., and the dragonfly *Pantala hymenaea* (Say) occasionally capture the adults.

The larvae of lacewing flies (Neuroptera) have been observed to capture the adults as they emerge.

An unidentified mite is occasionally found feeding on a midge pupa. Whether it is a predator or merely a scavenger is not known.

**CONTROL MEASURES**

**REMOVAL OF EARLY BLOOMING HEADS**

In July 1924 Baker tagged a number of sorghum heads as they were just beginning to bloom and left them exposed to normal infestation. Two of these heads were marked as checks to be left in the field. Beginning on the fifth day, and daily thereafter for 8 days, five heads were cut and allowed to fall to the ground between the rows, five were cut and placed in direct sunlight, and five were placed in the shade with the stems in a pail of water. Before emergence could take place all heads were enclosed in bags to capture the adults that might emerge. In this experiment all heads left standing (the checks) and all stood in water gave emergence in normal time. There was no emergence from any of the heads allowed to fall in the field or placed in direct sunlight.

This experiment was repeated by L. C. Woodruff in the cooler weather late in September and early in October 1925 in a slightly different form. Two heads were left as checks, and the daily cuttings were treated as follows: Four heads were allowed to fall between the rows, four were placed on the ground in the sun, four were placed on moist soil, and four had the stems inserted in moist soil. The plot of ground for the last two series was watered at intervals to keep the soil damp.

In this experiment the heads on moist soil and those with the stems inserted in moist soil gave emergence in most cases from 1 to 2 days earlier than the checks left standing in the field, possibly because of the greater heat near the ground. Those cut on the fifth day after they had begun to bloom and allowed to fall between the rows gave no emergence, but those cut on the sixth day and thereafter gave emergence as early, on the average, as did the checks. None of the heads cut and placed in direct sunlight gave emergence excepting those cut on the fifteenth day after blooming. Several light showers occurred during the time of this experiment.

From these experiments it would appear safe to let the early-rogued heads fall in the field during the heat of the summer, but as the season becomes cooler in the fall the rogued heads cut after the fifth day from blooming should be removed.

**PLANTING PURE SEED**

As already shown, the shorter the blooming period is, the lighter will be the infestation likely to develop. In fields where pure seed is used and the crop is induced to bloom within the space of a few days, the loss from the midge is usually negligible. On the other hand, uneven
blooming resulting from the use of mixed varieties is almost always followed by heavy losses. Advantage has been taken of these facts to such an extent that serious losses are now seldom experienced by the better informed farmers in the vicinity of San Antonio.

In one series of experiments it was planned to build up a complete infestation and then attempt to destroy it and immediately produce a crop comparatively free from the sorghum midge. Three consecutive plots were planted at 2-week intervals, thus giving continuous opportunity for oviposition. The infestation was thus built up until every kernel in the third plot was destroyed. The fourth plot, or main crop, was planted 2 weeks after the third with as uniform a blooming strain of hegari as could be found. The crop on the first three plots was cut and hauled away and the ground cultivated on the day before the first blooms appeared in the main crop. A crop sustaining only 9.7 percent infestation was thus produced in spite of the presence of a Johnson grass-infested field across the road to the north and a field of sumac sorghum hay 150 yards to the southeast. This test was repeated in four different years with similar results and demonstrated the value of using pure seed of a uniformly blooming strain and the elimination of immediate sources of infestation in preventing serious damage by the midge. The tests also indicate that early planting is not necessary in the control of the sorghum midge provided proper attention is given to other control measures.

**Planting Resistant Varieties**

A total of 43 varieties of saccharine and nonsaccharine sorghums and in addition the various broomcorns and related grasses were grown in an effort to find a variety showing resistance to the sorghum midge. In the list which follows several of the varieties were furnished by the Bureau of Plant Industry and the names are followed by the Cereal Investigations Number. All varieties were not planted the same year, but hegari and feterita were present every year and were used for comparison.

### Sorgkums

- White durna
- Feterita
- Spur feterita
- Dwarf feterita
- Dwarf hybrid feterita
- Hegari
- Dwarf hegari
- Chiltex
- Ajax
- Blackhull kafir 158
- Standard kafir C. I. 204
- Red kafir C. I. 34
- Sunrise kafir C. I. 472
- Dawn kafir C. I. 949
- Dwarf Blackhull White kafir
- Reed kafir
- Sunrise kafir
- Smith milo X kafir
- Manchu kaoliang C. I. 171
- Barchet kaoliang C. I. 310
- Standard Yellow milo C. I. 234
- White milo C. I. 362
- Dwarf Yellow milo C. I. 332
- Dwarf Yellow milo
- Holloman milo
- Double Dwarf Yellow milo
- Beaver milo
- Bishop
- Shallu
- Freed sorghum S. P. I. 29166
- Darso
- Shrock
- Sumac sorgo
- Red Amber sorgo 77
- Black Amber sorgo
- Orange sorgo 113-A
- Honey sorgo 20350
- Collier sorgo 19770
- Dwarf Java sorgo S. P. I. 39269
- Dakota sorgo S. P. I. 36998
- Gooseneck sorgo
- Atlas sorgo
- Sugardrip sorgo
Other host plants

- Evergreen broomcorn
- Evergreen Dwarf broomcorn
- Acme broomcorn C. I. 293
- Sudan grass
- Johnson grass

So far no varietal resistance has been definitely shown and all varieties seem to be attacked to the same degree. Such differences as were observed at San Antonio appeared to be due to greater uniformity in blooming in some varieties than in others or to the influence of varied growing conditions in different plots on the length of the blooming period. Cowland (3) states that in Sudan some varieties seemed to be more resistant than others.

**DATE AND RATE OF SEEDING**

As shown by Karpel' and his associates (11), varieties of sorghum differ greatly in their reaction to date and rate of seeding. Some varieties, such as hegari and the feteritas, require a warm soil in which to germinate, while the kafirs will tolerate a much cooler soil and can be planted much earlier. In general, as shown in their report, late planting, i.e., from May 15 to June 15, resulted in a more uniform and rapidly growing crop, with larger yields, than did earlier planting. Planting early so as to produce a crop before the midges become abundant has often been advocated, but this has not always been found possible, and early planting is not always necessary where other control measures are followed.

The rate of seeding is somewhat dependent on the date of seeding and the condition of the seedbed, as it is necessary to use more seed to obtain a good stand where conditions for germination are unfavorable. The tillering habit of the variety chosen must be considered also in determining the rate of seeding. Some varieties produce many tillers when the stand is thin. These tillers produce heads somewhat later than the main stalk and so extend the blooming period of the crop. The midge may develop on the early central heads to such an extent as seriously to infest the tillers which later develop into the major portion of the crop. A more uniformly blooming crop may be grown by planting thickly enough to secure a good uniform stand and to discourage the production of tillers.

**CULTIVATION**

Owing to their starchiness sorghum seeds rot very easily if conditions are not favorable for prompt germination. The sprouts are weak and often unable to penetrate a cloddy or crusty soil. Therefore a good fine and loose seedbed is essential in securing a uniform stand. Later cultivation should be that which will assist in producing a rapid and uniform growth and blooming of the crop.

**INSECTICIDES AND REPELLENTS**

Since the sorghum midge spends its entire life, except for the brief adult period, concealed within the spikelet, it is evident that not much can be done in the way of control with insecticides. The adult does not feed sufficiently to make it possible to use a poisoned bait. Furthermore, any such poisoned bait would probably be dangerous
to livestock later. A number of repellents have been tried, some of which seem to offer some relief, but when the cost of treatment is considered in relation to the value of the crop it appears that such methods are not practical.

SUGGESTIONS FOR CONTROL.

The losses of grain from this insect in sorghum fields are due (1) to midges that come from outside sources and (2) to midges produced within the field. Considerable loss can be prevented by putting into effect the following recommendations, some of which are suggested by Gable, Baker, and Woodruff (8):

1. Use pure seed of as uniformly blooming a strain as is possible to obtain.

2. Prepare a good seedbed and cultivate the field to produce as uniform a crop as possible.

3. Space plants so as to produce the smallest number of tillers that will give a satisfactory yield.

4. Plant at the time of the year best suited for the variety selected. Planting can be made at any time of the season provided a uniformly blooming crop is produced.

5. Prevent Johnson grass from producing heads in or near the sorghum field previous to the blooming of the crop.

6. If Johnson grass or sorghum hay is produced near the field it should be cut and removed several days before the grain crop comes into bloom. Grass that cannot be cut before the sorghum crop begins to bloom should be left until blooming is completed. Cutting such hay while the sorghum is blooming will cause the adults emerging from the cut grasses to go to the sorghum to oviposit.

7. Heads that bloom much before the main crop should be destroyed. If such heads are cut within 5 days after first blooms appear, they can safely be left on the ground. If cut later, especially in the fall crop, they should be removed from the field before midge emergence can take place.

8. Locate the sorghum field as far as possible from all outside sources of infestation such as earlier sorghum, Johnson grass, Sudan grass, or broomcorn.

9. If two plantings are to be made near each other, they should be placed so that the prevailing wind will blow toward, rather than from, the earlier field. The same would apply to other known sources of infestation.

10. Cultivate or burn fields of Johnson grass early in the spring to destroy hibernating midges before emergence occurs.

11. Where sorghum grain is threshed, burn or plow under all refuse not fed to stock before the spring emergence of midges.

SUMMARY

The sorghum midge causes serious losses in grain and seed production of various sorghums. The insect was first recorded from Alabama in 1895 and was described from material sent from Texas in 1898. It breeds abundantly on all varieties of sorghums and their allies, broomcorn, Johnson grass, and Sudan grass. Since it is not known to breed normally on any native plant, the suggestion is made that the sorghum midge is probably of foreign origin and that it may be identical with Contarinia caudata Felt from southern Asia.

The midge larva extracts the plant juice from the developing seed, thus blasting it.

The eggs are cylindrical, with a fine tapering appendage. The egg capacity of the female has been recorded as from 28 to 124. The incubation period is from 42 to 60 hours.

The larva is shown to have well-developed mouth parts and digestive tract, thus refuting earlier statements that the larva absorbs its nourishment through the body wall.
The newly hatched larva is nearly colorless and closely resembles the egg. As it grows it becomes pink and finally a dark orange. The head and fore part of the body are retractile. Most of the larvae pupate in summer after about 9 to 11 days of larval life; others, from any generation, form cocoons in which they may stay till late in the year, or pass the winter, or they may hold over for 2 or 3 years. The shorter life cycle of this midge may be completed in from 13 to 16 days. Only dormant cocooned larvae are capable of living for any extended time. The species has probably been distributed in seed and hay in this form.

Spring emergence from cocooned larvae is stimulated by rain and occurs in from 10 to 22 days after a rainfall, depending on the temperature during the intervening period.

The adults usually do not live more than a day. The percentage of males to females was 44.7 to 55.3 from overwintered larvae, and 35.6 to 64.4 from summer-formed pupae.

Ordinarily 13 generations occur during the growing season in the vicinity of San Antonio, Tex.

Oviposition occurs while the spikelets are in bloom. The female deposits only one egg at a time within the spikelet but may return later or be followed by others. Thirteen larvae have been known to develop within a single spikelet.

The most serious infestations of the sorghum midge are due to the adults which develop within the field on Johnson grass or early blooming heads of sorghum.

The parasites *Aprostocetus diplosidis* Cwfd. and *Tetrastichus* sp., abundant in 1910, have disappeared and another hymenopterous parasite, *Eupelmus popa* Gir., first collected in 1920, has taken their place and is the only parasite that has been seen since 1929. The life cycle of *E. popa* follows very closely that of the sorghum midge. Ants and spiders found on the sorghum heads are the most active predators.

Suggested control measures are those which eliminate the sources of infestation and particularly those which produce a short, even blooming period. Such measures are proper tillage and the use of pure seed of a uniformly blooming variety so that blooming is completed before a generation of the midge can develop within the field.

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(5) ———


