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DIVISION OF ENTOMOLOGY

The Sorghum Webworm (*Celama sorghiella* Riley)

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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With the rapid extension and increased production of grain sorghums in Texas during recent years, the economic importance of the sorghum webworm has been accordingly extended. This insect, which feeds upon the ripening grain, has proved most destructive in the humid regions throughout the eastern portion of the State. The development of injurious infestations depends largely on prevailing weather conditions, and serious outbreaks are most likely to occur during wet seasons.

The insect passes the winter in the worm or larval stage on the sorghum plants. Pupation occurs the following spring and the adults or moths begin to emerge about April 1. Shortly thereafter the moths start to lay eggs, but multiplication proceeds slowly up to about the middle of the growing season. After this time, however, the insect increases rapidly and therefore injures late planted crops more severely. Rearing records indicate that six complete generations or broods and a partial seventh are produced during a season.

The life cycle includes the three usual developmental stages; viz., the egg, larva, and pupa. The eggs are laid singly and attached to the plant with a cement-like substance. The incubation period averages 3 or 4 days in mid-season and 5 or 6 days during the early or late part of the season, when temperatures are lower. The larva or worm may molt four to seven times, but normally there are five developmental instars. Rearing records indicate that the average period required to complete larval growth is about 13.5 days. Pupation occurs within a cocoon, which is spun by the larva on the food plant. The time required for pupal development varies from about 5 to 9 days and averages slightly less than 6.5 days. The adult is a whitish moth with a wing expanse ranging slightly over a half inch. It is relatively long lived, more active at night, and for this reason not commonly observed in the field. In close confinement the maximum number of eggs laid was 169, but dissections indicate that upwards of 200 eggs per female may be laid under field conditions.

Control of the sorghum webworm by the use of insecticides is not practical and chief dependence must be placed in cultural measures. Clean-up practices after harvest and timely planting are most important. Stubbles should be plowed under thoroughly during the winter and Johnson grass areas burned over to reduce the overwintering population of worms. Crops timed to mature by mid-season are invariably injured the least. Although the sorghum webworm is attacked by four or five different parasites, these are not effective in preventing the development of injurious infestations.

CONTENTS

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Grain sorghums in Texas are attacked by several different species of insects among which the sorghum webworm, *Celama sorghiella* Riley, is one of major importance. This insect has been known for many years as an enemy of grain sorghums, but it attracted little attention in this State until the past decade or two. With the rapid extension and greater production of these crops, the potential economic importance of the sorghum webworm has accordingly been increased. The insect has proved most destructive in humid regions with an average annual rainfall of 30 inches or more. The occurrence of heavy infestations of worms apparently is determined in large measure by prevailing weather conditions. When the latter are favorable for rapid multiplication of the insect, from 25 to 70 per cent of the seed may be injured or destroyed. On the other hand, extensive damage is rarely produced during seasons characterized by prolonged spells of hot, dry weather.

The sorghum webworm feeds upon the ripening grain and does not attack other parts of the plant. The contents of the individual kernels may be partially or completely consumed, leaving only the outside hull intact. Frequently the corn earworm, also commonly known as the cotton bollworm, *Heliothis obsoleta*, may be found feeding on grain sorghum heads in company with the species here under discussion. Although they produce a similar type of injury, the two species are not to be confused. The sorghum webworm is a small, sluggish caterpillar with a somewhat flattened body, which is thickly clothed with spines and hairs. It is greenish in color and marked with four red to brown longitudinal stripes above. These items readily distinguish it from other lepidopterous larvae which may be found attacking the heads. Although the insect resumes activity early in the growing season, it multiplies slowly until grain sorghums have reached an attractive stage for food, and thereafter the increase is much more rapid. Consequently, heavy worm populations in crops are a more common occurrence during late summer or early fall.

Prior to 1932, when the present biological study of the insect was begun, little information was available concerning its life history, habits, or control. The observations and data presented in the Bulletin were all recorded at College Station or vicinity during the seasons 1932-33 to 1935-36, inclusive.

SYSTEMATIC HISTORY

The sorghum webworm was first described in 1882 by Riley (15) as *Nola sorghiella*, from specimens taken in Mobile County, Alabama. In 1890, Möeschler (14) described the same insect as *Nola portoricensis* from Porto

Rico. Dyar (4) published a brief descriptive note on the larva under the original name in 1891 and another in 1899 under the genus *Roeselia* (5). In 1900 Hampson (9) referred the species to the genus *Celama*, and sunk *Nola portoricensis* Möeschler as a synonym. The combination *Celama sorghiella* was used for the insect by Dyar (6) in 1902 and by Smith (16) in 1903. Six years later the species was referred to the genus *Nigetia* (1), under which name it was also mentioned in 1916 by Chittenden (3). The following year Barnes and McDunnough (2) again placed the species in the genus *Celama*. Most subsequent authors have accepted this generic reference and the sorghum webworm is now known as *Celama sorghiella*.

Celama sorghiella (Riley).

Nola sorghiella Riley, 1882, Rept. U. S. D. A., pp. 187-189, Pl. 11, Fig. 1.—Dyar, 1891, Psyche, Vol. 6, p. 110.

Nola portoricensis Möeschler, 1890, Abh. Senck Ges., Vol. 16, p. 118.

Roeselia sorghiella (Riley) Dyar, 1899, Can. Ent., Vol. 31, p. 61.

Celama sorghiella (Riley) Hampson, 1900, Cat. Lep. Phal., Vol. 2, p. 21.—Dyar, 1902, Bul. 52, U. S. N. M. No. 4048.—Smith, 1903, Check List Lep. Bor. Am., No. 900.—Barnes and McDunnough, 1917, Check List Lep. Bor. Am., No. 843.—Wolcott, 1936, Jr. Agr. U. Porto Rico, Vol. 20, p. 414.

Nigetia sorghiella (Riley), 1909, U. S. D. A. Yearbook for 1908, p. 570.—Chittenden, 1916, U. S. D. A. Bul. 363, p. 14.

COMMON NAMES

The larval stage of *Celama sorghiella* has been generally referred to in literature under the common name of sorghum webworm. In describing the nature of the damage produced, Riley (15) stated, "The sorghum heads sent were for the most part so interwoven with silk as to form a compact mass, in which was profusely mixed the whitish excrement of the larva. Running through the mass were numerous delicate tubes, forming channels, through which the larvae passed from one seed to another, unexposed to the attacks of parasites." Although Riley has used an apparently descriptive common name where this type of injury occurs, it should be pointed out that no extensive webbing up of sorghum heads by the insect was observed in the present studies either in the field or in the laboratory. Even in case of unusually heavy populations, the amount of silk spun by the larvae among the kernels of grain was not conspicuous. The originally suggested term of webworm can hardly be considered descriptive of the larva or the nature of the injury produced, at least throughout the Southwest. Haseman (10) also noted that the larvae do not spin very much silk in the sorghum heads, and used the common name "sorghum worm" which seems more appropriate for the species as a pest on grain sorghums. However, since the combination "sorghum webworm" has been officially adopted by the American Association of Economic Entomologists, it is herein used as the approved common name for *Celama sorghiella*.

DISTRIBUTION

The sorghum webworm is widely distributed in Texas east of the 98th meridian. In general, this includes the humid region of the State in which the average annual rainfall ranges from 30 to 45 inches. These conditions seem to approach the optimum moisture requirements of the insect as evidenced by the fact that the western limits of its common occurrence follow the general trend of the line which divides the humid and subhumid regions (Fig. 1). In the drier or subhumid region the sorghum webworm is generally less abundant but may increase to damaging proportions during wet or especially favorable seasons.

The counties from which the insect has been definitely recorded are indicated in Figure 1. The general range of distribution, especially in the region of East Texas, probably includes many additional counties from which it has not yet been reported. There are no authentic records of the

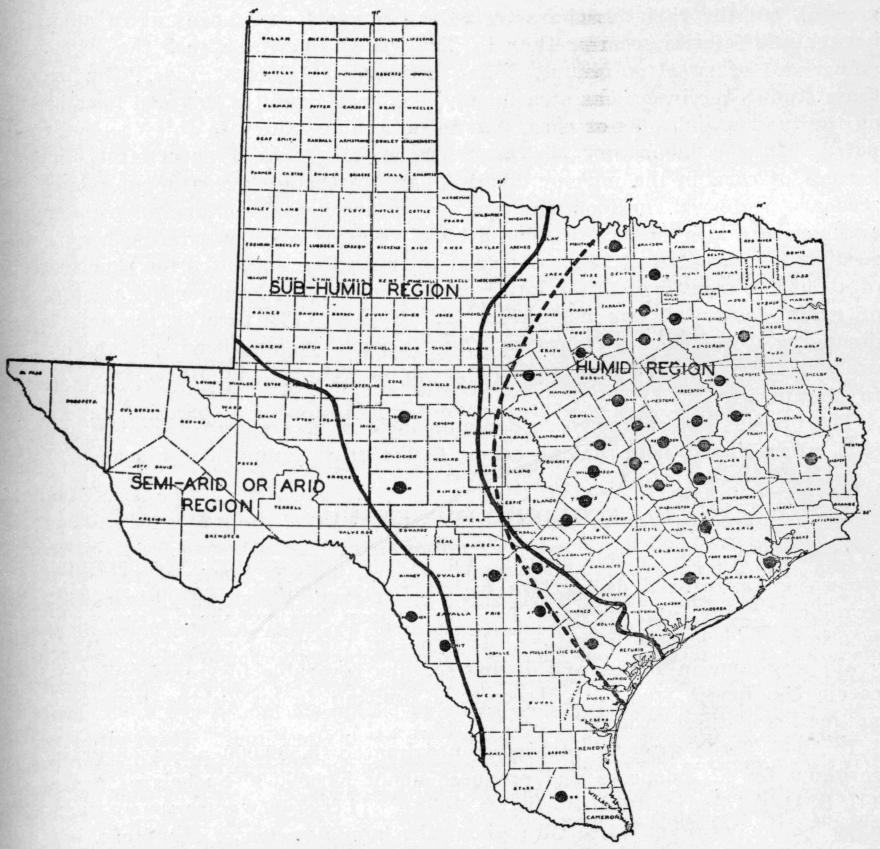

FIGURE 1. Distribution of the sorghum webworm. Solid lines divide the climatic regions; broken line the approximate western limit of serious injury by the insect. Counties from which the insect has been recorded are indicated by dots.

insect from the important grain sorghum producing region in Northwest Texas. The climate in that region seems too dry for the sorghum webworm to become permanently established as a pest of economic importance.

In the United States its geographical range includes the Gulf and South Atlantic states besides Indiana, Illinois, Tennessee, Missouri, Kansas, Oklahoma, and Arkansas (8, 10, 11, 12). The northernmost recorded limit of distribution is Nebraska, where the insect was found damaging stored corn (13). It appears most abundant in the southern part of its range and is apparently of greatest economic importance in the Gulf Coast states.

Outside this country the insect has been recorded from the Canal Zone, Panama by Dyar (7), and from Porto Rico by Wolcott (17).

FOOD PLANTS

Sorghum webworm larvae feed upon the seed of grain sorghums in general, but the varieties characterized by compact seed heads as in milo, hegari, and feterita seem preferred. The worms likewise attack the developing seed of sweet sorghums, Sudan grass, and Johnson grass. During these studies the insect has occasionally also been found in the field feeding on the tassels and silks of corn, but no noticeable injury to this crop was noted. In the laboratory the larvae have been reared successfully on kernels of corn in the milk or dough stage. Although green or succulent seed are preferred for food, the ripe or mature kernels of grain sorghum and corn are also subject to some attack. Worms confined on ripe hegari seedheads in the fall of 1932 continued their feeding activities for a period of about two months or to the latter part of December; however the amount of grain destroyed was not extensive. Hyslop (13) records the insect damaging stored corn in Nebraska. Broom corn, rye, and heads of timothy are also listed as food plants of the sorghum webworm by Haseman (10) in Missouri.

The present list of known food plants includes a variety of species, but it is interesting to note that all belong to the grass family, Gramineae.

ECONOMIC IMPORTANCE

Although known in this country for over a half century, the sorghum webworm has proved destructive in but rather limited areas of its geographical range, and perhaps for this reason has not been frequently mentioned in economic literature. It is one of the major pests that attack grain sorghums in Texas, and during seasons favorable for rapid multiplication the insect frequently becomes a limiting factor in the profitable production of these crops.

In 1935 Texas growers planted approximately 5,500,000 acres of grain sorghum for all purposes and produced about 53,000,000 bushels of grain (U. S. D. A., Agricultural Statistics, 1936). This crop was seriously damaged by the sorghum worm throughout the humid region of the State, but there are no records available by means of which the reduction from full yields per acre can be measured accurately. In local fields, however, 30 to

40 per cent of the grain crop was damaged, and losses were considerably greater in the late plantings and the second crops.

The losses in grain yields from sorghum webworm attack vary greatly from year to year and are closely correlated with prevailing weather conditions. During growing seasons characterized by rainy spells, crops may have practically all the grain destroyed by the worms; this is especially true of crops planted late. In contrast, little or no damage is produced by the insect during periods of drought, as were generally experienced in the growing season of 1934.

The economic status of the insect may be described as a potential limiting factor in the production of crops of grain sorghum seed throughout the eastern or humid region of the State.

DESCRIPTION OF STAGES

Egg

Viewed from above the egg is roundish to broadly oval in outline and flattened dorsoventrally. The height slightly exceeds one-half the maximum diameter. The shell is rather thick, and under magnification the flattened surfaces show characteristic pentagonal and hexagonal reticulations which are more deeply impressed on the upper than on the lower or attached side. Laterally these sculptured surfaces are joined at regular intervals by fine vertical ridges alternating with rows of well defined pit-like depressions.

The eggs are white with a pale greenish yellow tinge when laid, but change to straw yellow within a day or two, and to deeper yellow or brown as the embryo approaches complete development.

In size the eggs are slightly variable, ranging from 0.44 to 0.47 mm. in maximum diameter, and from 0.22 to 0.29 mm. in height. Measurements of ten eggs selected at random averaged 0.46 and 0.26 mm. in maximum diameter and height, respectively.

Larva

The newly hatched larva or caterpillar averages about 0.7 mm. in length and is pale greenish but turns darker in color soon after feeding begins. The body is rather slender, subcylindrical in cross-section, and is sparsely clothed with fine hairs. The latter arise from a transverse row of inconspicuous wart-like swellings or tubercles at the middle of each segment. The hairs along the lateral margins and at the anterior and posterior extremities are longest and some of these slightly exceed the total body length. Viewed from above, the pale or greenish head is fully exposed and slightly wider than the thoracic segments. Locomotion is accomplished by means of three pairs of well developed thoracic legs and four pairs of stout fleshy prolegs. The larva, throughout its period of development, is rather inactive and travels slowly or is sluggish in habit. Prior to the time of each molt the larva attaches itself quite securely by spinning a thin layer of silk on the surface of the plant. These silken layers are

rather inconspicuous and there is no tendency to web up the entire head of grain even in case of the heaviest infestation. Active larvae when disturbed prevent dislodgment from the plant by attaching themselves with a silken strand much in the manner of the common spring canker worm.

With each succeeding molt the larva increases in size and assumes a somewhat flattened and more compact appearance. After the first molt the tubercles become more prominent and most of the slender hairs of the first instar are replaced by shorter sharp-tipped spiny bristles, which are increased in number during the intermediate molts. Coincident with these changes color markings become apparent. The latter consist of variable reddish to brownish black stripes, which extend over the four longitudinal rows of tubercles. These color stripes are most defined just prior to each of the final three or four molts.

The mature larva is rather small, somewhat depressed, and about five or six times longer than broad. In dorsal aspect the sides taper slightly from the middle toward each broadly rounded extremity. The head is ordinary in size, shining pale brown, and more or less retracted beneath the first thoracic segment, which bears a well defined shield thickly clothed with bristles and hairs. Under magnification, the surface of the body is granular and faintly subshining. The ground color is pale green interrupted above by four longitudinal red to blackish stripes, which extend from the anterior margin of the first thoracic segment to apex of the abdomen. Each body segment bears three prominent tubercles above and a much smaller and less conspicuous one situated subventrally. The three uppermost tubercles of each segment are thickly beset with erect and outwardly directed bristly spines of varying lengths. This dorsal spinose vestiture is undoubtedly an effective protection to the larva from attack by enemies. To man, the spines may produce a discomforting epidermal irritation when brought in contact with the arms, face, or neck. Besides the spines just mentioned each of the lateral tubercles bears one or more long sensory hairs. Similar hairs are also present on the upper tubercles at each extremity of the body. The inner margin of each uppermost tubercle on the seventh and eighth abdominal segment bears a characteristic dense row of rather even black-tipped short spinose hairs which are directed inwardly. The ventral surface is pale greenish in color with the legs slightly infuscated on the outer side.

Measurements of 20 mature larvae collected from succulent grain sorghum heads in the field averaged 12 mm. in length and 3 mm. in width; the extreme length ranged from 9 to 14 mm.

Pupa

The pupa is reddish brown, rather slender and subcylindrical in cross section. The faintly subshining surface is apparently bare but under magnification shows scattered delicate or inconspicuous short pale hairs on the body segments, which have a finely granular appearance.

Viewed from above, the cephalic extremity of the pupa is broadly rounded.

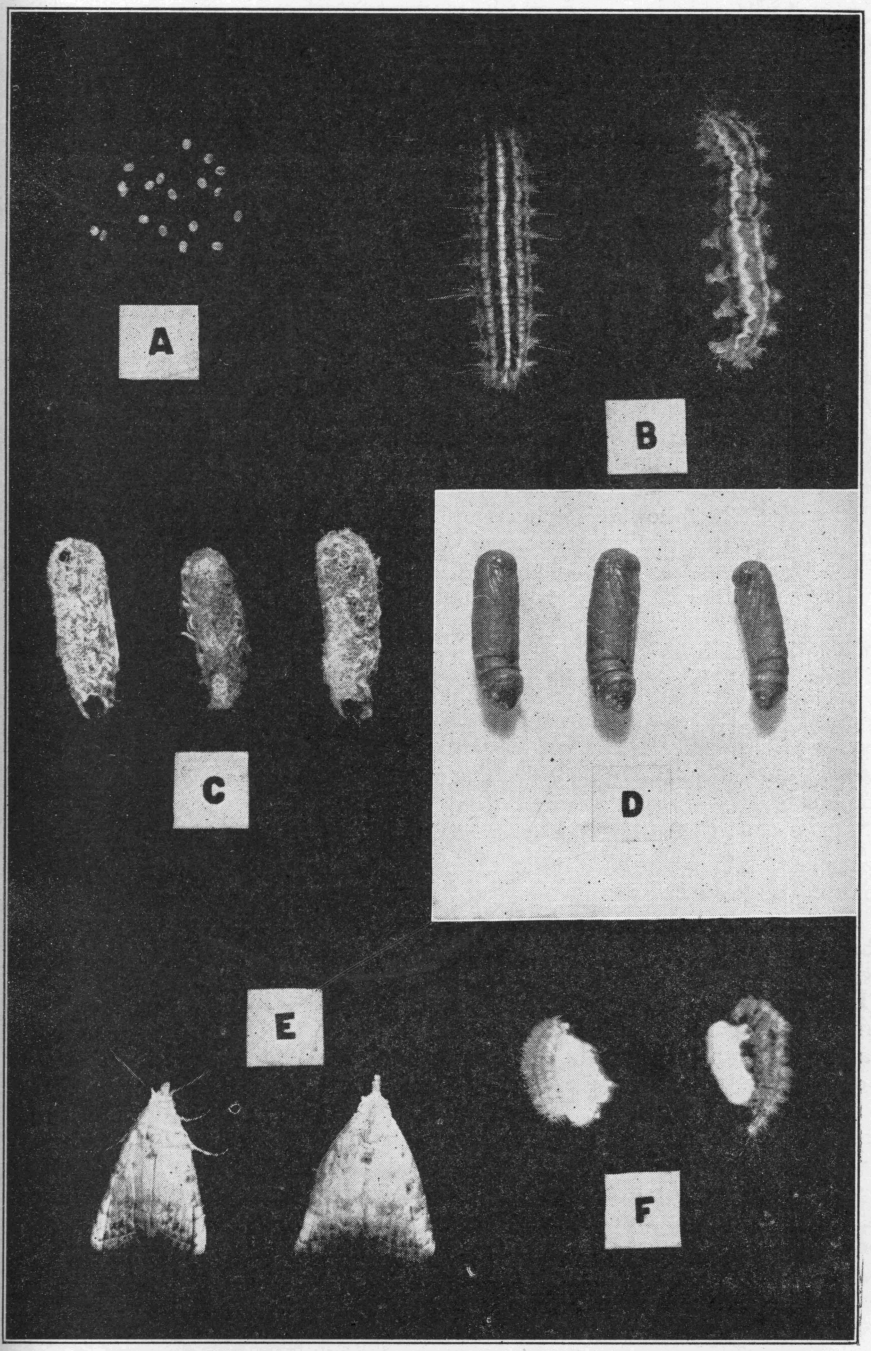

FIGURE 2. Successive stages of the sorghum webworm, all enlarged: (A) eggs; (B) mature larva, left dorsal and right lateral view; (C) cocoon; (D) pupa; (E) adult or moth; (F) larva killed by attached parasite.

The thoracic and abdominal segments are clearly defined and practically uniform in width to the base of the seventh abdominal segment from whence the sides taper rather sharply inward to a blunt cone-shaped apex, which is without any specialized spines or hooks. The surface of the abdominal segments is smooth above but more or less noticeably wrinkled on the sides of all except the first and narrowed apical ones. The spiracles are slightly infuscated, ordinary in size, with the pair on sixth segment a trifle larger than the rest.

The ventral surface of the pupa is generally paler than the dorsal coloration, and, depending on age, ranges from pale yellow to brown. The frontoclypeal suture is vaguely impressed and broadly concave at the middle. The labrum, pupal eyes, genae, and mandibles are all distinctly indicated. Both the meso and metathoracic legs extend well beyond the wing tips, but the antennae are distinctly shorter, hardly reaching beyond the basal third of the fourth abdominal segment. The sutures which define the prothoracic legs are much longer than the maxillae and extend almost to the middle of the third abdominal segment. The wings entirely cover the three proximal abdominal segments, and all but the outer posterior angles of the fourth. The following segments are rather loosely united and movable. Both the genital and anal openings are moderately large and slit-like. When transformation is complete, the segmentation of the adult antennae and legs is rather distinctly visible through the pupal skin.

The pupa is subject to some variation in size, ranging from 6.0 to 9.5 mm. in length, and from 1.5 to 2.5 mm. in width. Measurements of ten individuals reared in confinement averaged 8.5 and 2.0 mm. in length and width, respectively.

Adult

The adult sorghum webworm is a small whitish moth with a wing expanse ranging from 12 to 16 mm. (Figure 2). The pattern of the wing is rather vague or poorly defined, and there is considerable variation in different specimens. The wings and legs in the male sex are usually more infuscated than in the female.

The upper surface of the forewing near the costal margin bears three characteristic tufts of suberect scales; the median one is situated slightly beyond the middle, and the outer one at about the apical third of the wing. These scales vary from yellow to brownish black but fade to pure white on the outer margin of each tuft. Except along the costal margin, the basal two-thirds of the wing surface is clothed with mostly whitish scales. Located about in the middle of this area a small roundish spot of yellow scales is usually present. Near the apical third of the wing there is a rather vague, more or less complete irregular cross band of yellow scales, and a second but more distinct band of deeper yellow scales along the apical margin. Basad of the yellow apical margin the scales are white intermixed with gray and brown, besides some scattered erect black-tipped ones which seem more loosely attached than the rest and apparently are lost early in the active period of the moth. The costal margin is clothed with brownish scales interrupted with white blotches that are usually

more defined toward the extreme tip. Apically the wing is beset with a dense fringe of flat dark-tipped scales and the hind border with pale or whitish hairs. The under surface of the fore wing is rather uniformly dark grayish with the scales becoming paler and fading to white near the basal region and along the narrow hind margin.

The hind wing is pure white over most of the upper surface. Beneath the coloration is the same except that the anterior border and the extreme apical margin are usually infuscated. The white scales in these regions are intermixed with gray ones and there is a small but distinct patch of dark brown scales located a little beyond the middle of the wing. The posterior border is clothed with dense long white hairs and the apical margin with flat scales, which are mostly white but sometimes flecked with gray near the anterior extremity.

The head is slightly deflexed, broader than long, and densely clothed with snow white scales over the entire frontal surface. Ocelli are absent. The eyes are brownish black, rather large, and prominent. The slender tapering antennae hardly equal one-third the length of the fore wing; they are yellow, ciliated on the under side, and the enlarged basal segment bears a conspicuous tuft of long white scales on the anterior edge. The labial palpi are porrect, with the elongated second segment somewhat compressed and covered by white scales mottled with gray or brown on the outer side. The tongue is spiraled, rather short, and apparently bare on its entire length. The occiput is gently convex, yellowish in ground color, and sparsely beset with scales.

Viewed from above, the thorax is distinctly wider than the head and is covered with a vestiture of mostly appressed white scales. Newly emerged specimens show a median dorsal tuft of suberect darker scales and two similar but less conspicuous ones on either side situated slightly behind the middle. These tufts of loosely attached scales are usually lost early in the active period of the moth. The densely scaled upper surfaces of the patagia are slightly elevated above the front margin of the pronotum and effect the appearance of a broad white ruff or collar which is narrowly divided along the median line. The pleural and the ventral surfaces of the thorax are smoothly scaled and pure white.

The abdomen is subcylindrical, rather robust, and about as wide as the thorax but tapers to a narrow apex. The scaling is generally appressed, smooth, and concolorous with the thorax. Near the base above there is a conspicuous tuft of gray and white scales which reach above the inner margins of the wings when the latter are in resting position. In both sexes the genital segments are thickly clothed with long white scale-like hairs.

The legs, except the tarsi, are whitish but the scaling on the outer margin is more or less infuscated. The tarsi are brown with pale annulations at the apex of the segments. The middle and hind tibiae are densely pale-haired on the hind edge and both bear long conspicuous spurs.

LIFE HISTORY AND DEVELOPMENT

Experimental Methods

All detailed observations on the life history of the sorghum webworm reported herein were made in a laboratory with screened sides within which temperatures and humidity approached natural conditions. Green or succulent Johnson grass seed and sorghum grain were used as food in rearing all larvae included in the life history studies. The first mentioned food plant was used only during the early part of the growing season or until the early planted local sorghum crops began to produce heads of grain.

For the purpose of securing records on oviposition, single pairs of moths of the overwintering brood and of each succeeding generation were confined, soon after emergence, in glass cylinder cages measuring 150 mm. long and 20 mm. in diameter. One end of each cylinder was covered with a single thickness of cheese cloth and the other stoppered with a moistened cotton plug wrapped in cheese cloth. The cotton plugs were renewed each morning and afternoon to keep a constant source of moisture available to the confined insects. Without access to water the mortality among the caged insects was noticeably increased. Dilute sugar solutions were tried as food, but these did not seem any more attractive, nor prolong the life of the moths in close confinement. Unsweetened water was therefore supplied to practically all individuals under observation for records on oviposition and longevity.

In confinement, moths seldom oviposited on the kernels of green sorghum grain provided for the purpose, but more commonly attached their eggs to the surface of the cage. Also, since the presence of an attractive larval food plant did not seem to stimulate egg deposition by the moths, most pairs were confined in empty cages for the daily and total oviposition records. At the end of each 24-hour period, the confined insects were transferred in single pairs to clean cages. This procedure was repeated daily throughout the life period of all individuals under observation. The eggs deposited during each day were kept in separate lots for observation on the duration of this developmental stage. When the eggs hatched, each young worm was isolated on fresh food in shell vials (100 x 20 mm.) with the open end covered with cheese cloth. Abundant fresh food was supplied to each larva during the morning and afternoon of each day in its developmental period. At the time of these operations, all individuals were carefully noted for molts until pupation occurred. The pupae were kept isolated in glass vials as in case of the larvae and examined twice daily for emergence of adults.

To obtain records during the hibernation period of this insect with respect to winter survival and spring emergence, grain sorghum stalks were collected after frost during the fall in local infested fields and placed in upright position in large screened cages which were situated under open field conditions. At the time of installation an adequate sample of each lot of caged stalks was carefully examined and the number of worms

recorded was used as a basis to compute the total number of overwintering larvae present in the stalks that were placed in each cage. This method of observation was utilized because the overwintering larvae usually secrete themselves behind the leaf sheaths of the stalks and cannot be counted accurately without undue disturbance of natural hibernating conditions. After emergence began in the cages during the spring, the number of moths was recorded and removed each day until emergence was completed. Winter survival as here considered is the ratio between the number of moths that emerged in the cages and the total number of worms which were installed during the previous fall season.

Seasonal History

In the region of South-Central Texas, sorghum webworm moths are active from April to November during favorable seasons. Adults of the overwintering brood of worms normally begin to emerge during the last week in March and oviposition begins soon thereafter. At this time grain sorghum crops are not commonly up in the field and eggs are deposited on other plants of the grass family. It has been noted that corn is sometimes selected for oviposition by the moths and there seems little doubt that Johnson grass is utilized more extensively for the same purpose. As the season advances the sorghum webworm population increases gradually until grain sorghum crops in general have reached an attractive developmental stage. After this time reproduction of the insect proceeds at a greatly increased rate until the occurrence of frost. However, the rate of increase in the field infestations is limited to a large degree by prevailing weather conditions. During seasons when protracted hot, dry spells occur in July and August, multiplication of the insect is greatly retarded and crop losses are generally less severe. On the other hand, the occurrence of ample rainfall and moderate temperatures during the summer months is usually followed by infestations of damaging proportions, especially on late planted crops.

Hibernation and Spring Emergence: The sorghum webworm passes the winter in the larval stage on the food plant. Locally, with the approach of decreasing temperatures during October and November, the worms gradually leave the heads of grain and move down on the sorghum stalks to protected situations behind the appressed leaves of the stalk sheath. Observations indicate that the larvae show no pronounced gregarious tendency during hibernation. They may be found distributed singly or in small groups along the entire length of the stalks. On warm days during the winter the larvae exhibit some activity and frequently crawl from place to place within the hibernating quarters; moreover they continue to molt at irregular intervals during the cold season. Except the mature larvae, all other developmental stages and the adults succumb during the dormant period. Although long-cycle or overwintering larvae were noted in the laboratory during September, the bulk of the hibernating brood in the field does not generally seek shelter before October. After this time

immature larvae continue to feed as long as conditions remain favorable. The late maturing individuals which enter winter quarters during November also commonly pass the winter successfully.

During the winter seasons 1932-33 to 1935-36, inclusive, infested grain sorghum stalks were caged for records on winter survival and spring emergence of the insect. The data secured in these cage experiments are presented in Table 1. It will be noted that about 10 to 17 per cent of the hibernating larvae or worms passed the winter successfully to emerge as adults during the four seasons under consideration. The variations in survival show no correlation with the minimum temperatures or the total rainfall recorded during the dormant period, December to March, inclusive. Weather conditions throughout the fall seem a more important factor in this connection. The heaviest survivals were recorded from installations made during fall seasons when succulent or late planted grain sorghum crops were available generally, until the bulk of the overwintering brood of worms had entered hibernation. The extent of survival is not a reliable index to the amount of injury that may be produced by the subsequent generations of worms during the growing season. The rate at which the insect multiplies is determined in large measure by the prevailing weather conditions. For example, in the spring of 1934 a heavy emergence of moths did not result in any extensive or destructive infestations during the hot, dry summer months that followed. On the other hand, a comparable spring emergence of moths in 1935 and 1936 was followed in each case by a wet growing season during which destructive infestations of worms developed on grain sorghum crops throughout South-Central Texas.

The overwintering worms begin to pupate when daily mean temperatures average 58 to 60 degrees F. Normally these effective temperatures are attained in March. During the dormant seasons here under discussion the emergence period of the moths averaged 10 weeks in duration, the extreme dates ranging from March 26 to June 13. The distribution of total moth emergence by months is also indicated in Table 1. In 1933 the peak of emergence occurred during the latter half of April, but during the three following years the adults did not emerge in maximum numbers until about the middle of May. Approximately 43 per cent of the moths emerged prior to May 1, and 97.4 per cent prior to June 1. The sex ratio among the moths of the overwintering brood was slightly in favor of males each year, but the differences in the number of each sex appear too small to be considered significant.

Number and Sequence of Generations: During 1934, six generations of the sorghum webworm were reared in the laboratory from April 21 to September 25. From the data recorded in Table 2, it may be observed

Table 1. Hibernation and spring emergence of the sorghum webworm at College Station

Year	Number of worms installed	Period of emergence	Per cent moths emerged during				Total number moths emerged	Sex ratio		Per cent survival
			March	April	May	June		Male	Female	
1932–33	2125	March 31 to June 8, 1933....	.54	71.97	26.41	1.08	371	195	176	17.46
1933–34	1400	April 9 to June 13, 1934.....	.00	17.05	80.11	2.84	176	89	87	12.57
1934–35	1200	March 27 to June 7, 1935....	.77	34.11	59.69	5.43	129	67	62	10.75
1935–36	5400	March 26 to June 11, 1936....	.33	46.93	51.74	1.00	603	311	292	11.17
		Average..	.41	42.51	54.49	2.59	320	166	154	12.99

Table 2. Number and sequence of generations of the sorghum webworm at College Station

Generation	Number of specimens	Date of		Length of life cycle (days)
		Egg deposition	Adult emergence	
First	1	April 21	May 22	31
	2	April 25	May 23 to 25	28–30
	11	April 26	May 22 to 23	26–27
	1	April 28	May 24	26
	19	April 29	May 23 to 28	24–29
	4	May 1	May 25 to 27	24–26
	2	May 3	May 30 to June 2	27–30
	5	May 4	May 30 to June 1	26–28
	1	May 8	June 3	26
	2	May 12	June 4	23
	15	May 13	June 4 to 7	22–25
	3	May 17	June 9 to 10	23–24
	1	May 18	June 7	20
Second	2	May 24	June 14	21
	3	May 27	June 17 to 19	21–23
	3	May 28	June 18 to 20	21–23
	19	May 29	June 19 to 23	21–25
	7	May 30	June 20 to 23	21–24
	4	May 31	June 21 to 22	21–22
	4	June 5	June 24 to 25	19–20
	5	June 7	June 28 to 30	21–23
	3	June 8	June 30 to July 1	22–23
Third	2	June 16	July 4 to 5	18–19
	2	June 18	July 7	19
	17	June 22	July 10 to 12	18–20
	28	June 23	July 11 to 14	18–21
	8	June 24	July 13 to 14	19–20
	6	June 27	July 15 to 16	18–19
Fourth	13	July 15	August 4 to 5	20–21
	1	July 16	August 5	20
	3	July 18	August 6	19
	4	July 20	August 9 to 10	20–21
	3	July 21	August 10	20
	7	July 28	August 16 to 17	19–20
Fifth	2	August 8	August 28	20
	5	August 11	August 30 to 31	19–20
	14	August 14	September 1 to 3	18–20
	9	August 15	September 2 to 3	18–21
	4	August 16	September 4 to 5	19–20
Sixth	3	August 31	Hibernated	.....
	11	September 1	September 25 to 28*	24–27
	5	September 2	September 27*	25
	8	September 3	September 27 to 28*	24–25
	4	September 4	September 29*	25
	3	September 5	Hibernated	.....

*Hibernated in part.

that a considerable overlapping of the successive generations occurs throughout the season. The second brood of moths, which are considered adults of the first generation, began to appear on May 22 and continued emerging up to June 10. The duration of the life cycle ranged from 20 to 31 days. Fifty moths of the second generation emerged from June 14 to July 1 and required 19 to 25 days to complete their development. The first moths of the third, fourth, and fifth generations emerged on July 4, August 4, and August 28, respectively. Individuals of these generations attained maturity in 18 to 21 days. Temperatures during the developmental periods of these generations were considerably above normal and effected

a heavy mortality among the caged larvae. Observations on the sixth generation included only 34 individuals, of which 11 hibernated as mature larvae; the remaining ones completed development and emerged as adults from September 25 to 29. These moths were paired in cages but failed to produce any eggs. However, when weather conditions remain favorable, reproduction continues in the field until late October, which allows sufficient time for the completion of a partial seventh generation in the latitude of College Station. It appears that the hibernating or overwintering brood is not restricted to larvae of any definite generation; also, that the number of generations which may occur during a season is indeterminate. During seasons when rainfall is normal or above, six complete generations and a partial seventh are probably the common occurrence in local sections of the State. The first three, which have developed for the most part by July 15, are usually too limited in numbers to produce extensive losses even in early planted grain sorghum crops. The fourth and subsequent generations produce the bulk of the injury and crops with grain in the milk or dough stage during September, or later suffer the greatest losses in yield.

Mating and Fertility

Moths normally attain sexual maturity within a day or two after emergence, but sometimes mate within the first twenty-four hour period of adult activity. Mating, either in the field or laboratory, rarely takes place during the hours of bright daylight. Paired individuals confined in 20 x 150 mm. glass cages copulated readily and remained connected during the act for varying periods of time ranging from about one-half hour to nearly two and one-half hours. Observations indicate that one successful mating insures the fertilization of at least the average number of eggs laid by caged females. Successive matings most likely occur especially in the field where the oviposition period is undoubtedly much more protracted than under caged conditions.

Paired moths confined in cages frequently failed to mate. The failures were most numerous during extended periods of hot, dry weather. In some instances the unfertilized females oviposited in an apparently normal manner, but the eggs failed to hatch and usually collapsed within three or four days. Near the end of the oviposition period caged females under observation occasionally deposited eggs which failed to hatch seemingly due to infertility. The number of such eggs noted, however, constituted a very small percentage of the fertile quota produced by any successfully mated individual. Field collected eggs which were kept under observation in the laboratory yielded larvae in practically all cases, indicating a high degree of fertility among the eggs laid under natural conditions.

Egg Deposition

The egg laying activities of the moths occur mainly in darkness, and consequently the act of oviposition was not commonly observed. The eggs are laid singly and usually on the flowering parts or seed of the food plant. They are rather securely fastened to the surface with a viscous

material which soon hardens on exposure to air. Although many of the eggs are attached to fully exposed parts of the plant, there is an apparent tendency among the confined females to select more or less protected situations in which to place the eggs. In cages containing sorghum seed, females oviposited much more frequently on the sides of the cages than on the food plant supplied for this purpose. Eggs so deposited hatched as readily as those placed directly on the sorghum seeds.

Egg deposition usually begins during the first week of April in the latitude of College Station. From this time on, oviposition in the field is continuous throughout the growing season. Most of the first generation eggs are deposited by May 20, but late emerging moths which mature from overwintering larvae may continue oviposition well into July. By this time fourth generation eggs are also being laid, indicating a wide overlapping of the oviposition periods of the successive generations.

In the field egg deposition seems restricted to plants of the grass family. In the early part of the season the sorghum webworm may readily develop on Johnson grass, and some eggs have been noted in the field on fresh silks and tassels of corn. However, sorghum crops in bloom or those with seed in the early stages of development are most attractive to the moths for oviposition.

Pre-oviposition Period: There appears to be no very definite pre-oviposition period. Moths reared in the laboratory were seemingly sexually mature upon emergence from the pupal cases. The time at which egg deposition begins may range from the first to the sixth day of adult activity. Newly emerged individuals paired in cages occasionally mated and the female began to lay eggs within the first twenty-four hour period after emergence. More commonly, however, the caged females did not begin oviposition until a day or two after attaining the adult stage.

Oviposition Period: In cages the duration of the oviposition period of the moth is subject to considerable variation. The maximum period noted was 16 days and the average period of 20 pairs of moths kept under observation during May and July totaled about 4.5 days. Since the moths do not withstand close confiinement readily during warm weather, the above records on the duration of the oviposition period are probably shorter than the maximum and average egg laying period under field conditions.

Number of Eggs Laid: The daily oviposition records of 20 females which were paired in cages immediately after emergence are given in Table 3. It will be noted that wide fluctuations occurred in the number of eggs laid during a twenty-four hour period and also in the total number deposited. The maximum number of eggs laid by a single female was 169. All moths under observation averaged slightly over 88 eggs per female. Dissections of the six individuals with the largest egg quota showed each to contain at the end of its active period additional eggs which were only partially developed. It therefore may be safely stated that under natural or field conditions the moth is capable of producing a considerably larger number of eggs than indicated by the maximum figure mentioned above.

Table 3. Daily oviposition records of twenty pairs of sorghum webworm moths

Date	Daily Mean Temperature Degrees F.	Pair Number																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
July 5, 1932	86.5	EP	EP	EP	EP																
6	86.5	0	3	0	0	EP	EP	EP													
7	85.0	13	46	84	24	0	0	0													
8	86.0	47	35	*	19	66	43	21													
9	83.5	41	0		0	5	14	49													
10	83.5	0	0			0	10	11													
11	85.0	0					7	0													
12	84.0	0					13	0													
13	83.5						0														
20	86.0								EP												
21	84.5								1												
22	87.0								53												
23	86.5								0												
24	86.5								0												
25	86.0								0												
26	86.5									EP	EP	EP									
27	87.5									0	65	32									
28	87.5									20	8	11									
29	88.0									17	0	10									
30	89.0									26	0	2									
31	88.0									5	0	2									
Aug. 1	90.0									10	0	0									
2	91.0									0		0									
May 3, 1934	75.0												EP								
4	81.5												67								
5	76.5												0	EP	EP	EP					
6	78.0												0	0	54	65	EP				
7	77.0												0	0	16	11	0				
8	76.5												0	0	10	14	2				
9	77.0												0	0	7	54	1				
10	75.0												0	0	5	14	0				
11	72.5												0	18	0	11	2				
12	74.5												0	28	10	0	6				
13	79.0												0	9	6	0	8	EP			
14	73.0												0	4	14	0	0	0			
15	63.0													1	0	0	0	0			
16	70.5													25	5		0	44	EP		
17	73.5													36	8			19	56	EP	
18	77.5													0	0			20	5	0	EP
19	76.5														0			15	0	0	42
20	78.0														4			5	0	55	24
21	78.0														1			6	0	18	18
22	78.5														0			0	0	3	24
23	81.5														0				0		51
24	77.0																		0		0
25	73.5																				0

EP—emerged, paired. *—incomplete record.

High temperatures seem effective in reducing oviposition. For example, the number of eggs recorded during July 1932, with daily mean temperatures ranging from 83.5 to 89 degrees F., averaged approximately 30 less per female than in May 1934, when the limits of the means were 8 to 20 degrees lower. Field observations in this connection also indicated a marked decrease in the egg laying activities of the moths during seasons characterized by protracted periods of hot, dry weather.

Incubation Period: Records on the incubation periods of 50 egg lots, including a total of 743 eggs, are presented in Table 4. The mean temperatures indicated are the averages of the daily extremes affecting the eggs of

Table 4. Incubation period of egg of Sorghum Webworm

Laid		Hatched		Lot egg days	Weighted average incubation period days	Average mean temperature
Lot number	Date	Date	Number eggs			
1	May 6, 1932	May 10, 1932	8	32	4.00	77.1
2	May 7,	May 11–12,	3	13	4.33	74.5
3	May 11,	May 16,	2	10	5.00	72.5
4	May 12,	May 16–17,	17	81	4.76	71.9
5	May 13,	May 18,	3	15	5.00	72.3
6	June 3,	June 8,	3	15	5.00	79.7
7	June 7,	June 12–13,	14	72	5.14	80.1
8	June 8,	June 13–14,	27	142	5.37	79.9
9	June 9,	June 13–14,	3	13	4.33	79.9
10	June 10,	June 14–15,	39	167	4.28	80.0
11	June 11,	June 15–16,	44	184	4.18	81.6
12	June 12,	June 15–16,	14	55	3.92	82.1
13	July 5,	July 8–9,	46	144	3.13	86.0
14	July 6,	July 9–10,	12	43	3.58	85.2
15	July 7,	July 10–11,	50	154	3.08	84.5
16	July 8,	July 11,	4	12	3.00	84.3
17	July 21,	July 24,	25	75	3.00	86.0
18	Aug. 12,	August 16,	7	28	4.00	83.5
19	Aug. 14,	August 17–18,	94	286	3.04	84.0
20	Sept. 4,	September 8,	6	24	4.00	79.1
21	Sept. 5,	September 9,	2	8	4.00	76.6
22	Sept. 7,	September 12,	2	10	5.00	76.1
23	April 25, 1934	April 30–May 1, 1934	2	11	5.50	70.1
24	April 26,	May 2,	11	66	6.00	69.7
25	April 29,	May 4,	19	95	5.00	72.4
26	May 1,	May 5,	4	16	4.00	76.1
27	May 3,	May 7,	2	8	4.00	77.7
28	May 4,	May 8–10,	5	26	5.20	77.9
29	May 12,	May 17,	2	10	5.00	72.0
30	May 13,	May 16–19,	8	40	5.00	72.7
31	May 17,	May 21,	3	12	4.00	76.3
32	May 24,	May 28,	2	8	4.00	72.7
33	May 27,	May 30–31,	3	11	3.66	76.6
34	May 28,	June 1,	3	12	4.00	79.1
35	May 29,	June 2,	19	76	4.00	79.5
36	May 30,	June 3,	7	28	4.00	78.7
37	May 31,	June 4,	4	16	4.00	79.7
38	June 5,	June 9,	4	16	4.00	84.1
39	June 7,	June 11,	5	20	4.00	83.7
40	June 8,	June 12,	3	12	4.00	83.4
41	June 22,	June 25,	17	51	3.00	84.8
42	June 23,	June 25–26,	29	85	2.93	84.0
43	Aug. 11,	August 14–15,	18	56	3.11	87.5
44	Aug. 14,	August 16–18,	31	96	3.09	86.5
45	Aug. 31,	September 3,	18	54	3.00	87.0
46	Sept. 1,	September 4,	17	51	3.00	82.1
47	Sept. 2,	September 6–7,	53	218	4.11	78.8
48	Sept. 3,	September 8,	18	90	5.00	76.5
49	Sept. 4,	September 10,	4	24	6.00	78.0
50	Sept. 5,	September 10–11,	7	39	5.57	79.1

each individual lot under observation. The time required for incubation of the egg varied from 2.93 to 6.00 days, depending in large measure on temperature and perhaps other factors. In mean temperatures of 80 to 82 degrees F., the incubation period ranged from 3 to 4 days; but when the mean dropped to 75 degrees or below, the time required for incubation was increased to 5 or 6 days. The weighted average incubation period for all lots under observation was 4.18 days.

It was found that all eggs laid during a twenty-four hour period and caged under apparently identical conditions do not necessarily hatch within the limits of a period of like duration. For example, from a total of 31 eggs laid on August 14, 1 hatched on August 16, 26 on August 17, and 4 on August 18. The occurrence of such variations appears to be the result of unknown individual differences and cannot be readily explained.

Hatching: As embryonic development proceeds, the original greenish white color of the egg changes to pale yellow, thence to a deeper or straw yellow, and shortly before hatching to brown. Details of the changes undergone by the developing embryo are largely obscured by the rather heavy and deeply reticulated structure of the egg shell. The young larva, when ready to hatch, is in a U-shaped position and occupies most of the space within the egg. The shell is broken usually along the upper and outer margin by the mandibles which operate with a pincer-like action. There appears to be no uniformity in either the shape or size of the exit hole made by different individuals. After the larva has gradually worked itself free from the egg it crawls away without feeding on the shell. The time required for hatching averaged approximately twenty-four minutes for seven individuals observed on July 8 and 10, 1932. The empty egg retains its original shape but may be readily distinguished from the unhatched egg by the glistening pure white color of the shell.

Larval Development and Feeding Habits

A total of 206 larvae representing five generations was reared to maturity under laboratory conditions from May 10 to September 26, 1932. The data recorded in these studies are summarized in Table 5. Four to seven larval stages were observed between the time of hatching and pupation. Most individuals, however, attained full growth by the end of fifth instar, indicating that usually five molts occur during larval development. It may be stated here that mature hibernating larvae frequently molt two or three times during the winter months and again as pupation occurs in the spring.

During the first four developmental stages the larvae molted after approximately equal feeding periods, which averaged slightly over two and one-half days. Normally the fifth larval stage includes the pre-pupal period and is a little more protracted than the preceding ones; the limits noted range from two to seven days. However the active or feeding period necessary to attain full growth in the fifth larval stage averaged but little longer than for any earlier instar. Based on the mean duration of the five normal instars, the time required for complete larval development was about 13.4 days.

Table 5. Duration of larval period of the Sorghum webworm

Date of oviposition 1932	Average mean temperature degrees F.	Instar	Duration of instar (days)			Number of records
			Maximum	Minimum	Average	
May	76.4	First	4	3	3.27	22
		Second	5	2	3.63	22
		Third	5	2	3.18	22
		Fourth	6	3	4.00	22
June	82.2	First	4	2	2.39	79
		Second	5	2	2.93	79
		Third	4	2	2.48	77
		Fourth	5	2	2.25	75
		Fifth	5	2	2.86	73
		Sixth	6	2	3.23	30
		Seventh	6	3	4.33	3
July	86.1	First	4	2	2.44	94
		Second	4	2	2.15	94
		Third	3	2	2.14	94
		Fourth	6	2	2.59	93
		Fifth	7	2	3.37	48
		Sixth	4	3	3.50	4
August	85.4	First	3	2	2.02	101
		Second	3	2	2.09	87
		Third	3	2	2.08	80
		Fourth	5	2	2.35	79
		Fifth	7	2	2.79	58
September	78.5	First	4	2	2.91	11
		Second	3	2	2.20	5
		Third	3	2	2.20	5
		Fourth	3	2	2.20	5
		Fifth	5	2	3.33	3
		Sixth	5	2	3.50	2

When preparing to molt, the larva ceases to feed, attaches itself to the food plant by thin layer of silken strands, and becomes quiescent. This period of inactivity usually extends from 6 to 12 hours and may be more protracted during the final stages of larval growth. Molting frequently occurs over night. In the molting process the skin loosens at the thorax and the old integument, with the head capsule attached, gradually moves off the posterior end of the larva. When the head has been freed the larva crawls out of the skin, and feeding is soon resumed. After the characteristic color markings and spinose vestiture of the larva have been developed, the molted skin is quite conspicuous and often remains attached at the point where it was shed. No larvae were observed to feed upon the cast skin. The time required for the successive molts was not definitely determined. General observations indicate that the process of molting may be completed in 15 to 30 minutes under apparently favorable cage conditions.

The newly hatched larva is rather sluggish in habit but begins to feed soon after it has emerged from the egg. During the early part of its active period, feeding is commonly confined to the succulent and tender flowering parts of the food plant. When green or succulent seeds only were supplied in cages, the young worms seemingly found it difficult to begin a feeding area, and the resultant mortality was high. But when the outer seed coating was cut open or partially removed, feeding began without delay

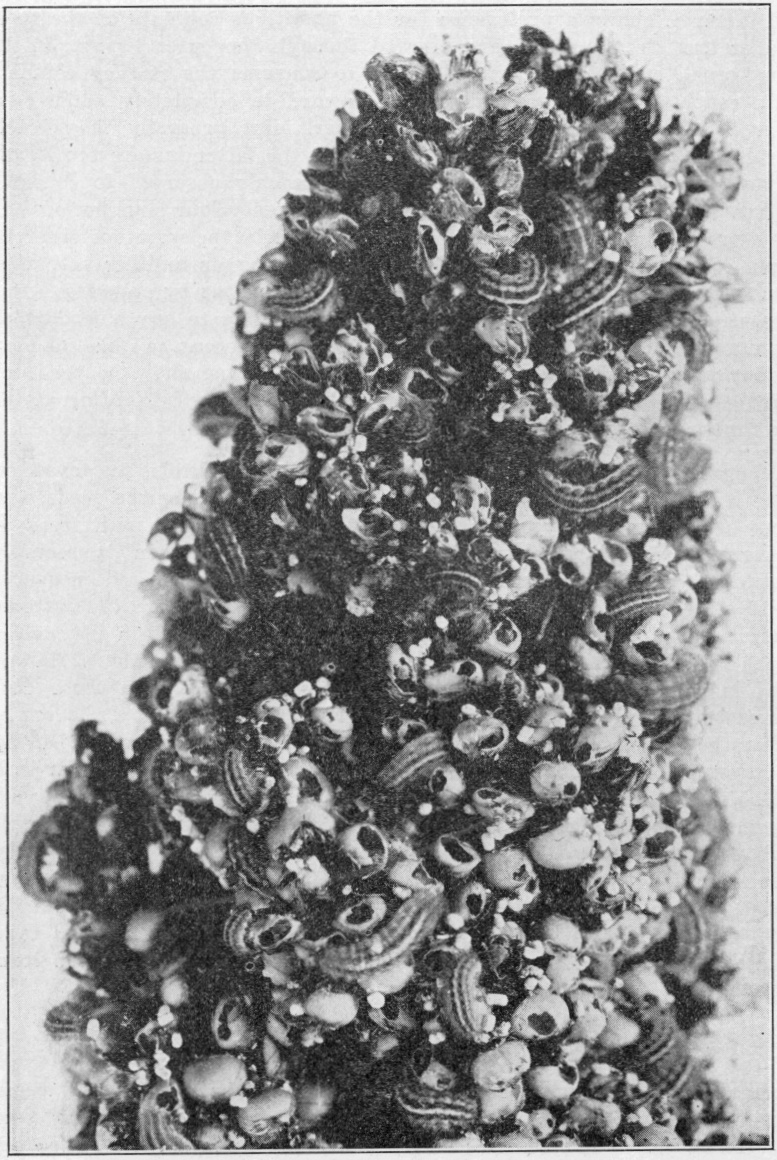

FIGURE 3. Grain sorghum head showing type of injury produced by heavy infestation of sorghum worms.

and the larvae developed satisfactorily. As growth proceeds, the larva requires a correspondingly larger amount of food, and after attaining the third instar it shows a preference for the nutritious contents of the seed. More or less circular holes are gnawed through the outer tissues of the grain kernel, and the larva then begins to consume the starchy contents within reach and may gradually move inward to completely hollow out the seed before leaving it to attack another. But generally the kernels of grain are only partially eaten out. During the latter instars the larvae are voracious feeders and in cages were commonly observed to consume the greater part of a dozen or more seeds in a twenty-four hour period.

Throughout the active period in each instar the larvae were not observed to spin any webs for protection during the feeding or molting activities. When disturbed, young larvae often suspend themselves by spinning a fine silken strand on which they sway to and fro, clinging to any object which they may encounter. Inter-plant migrations may occur in this manner, but they are probably not very extensive. The larvae show no tendency toward cannibalism, and upwards of 200 individuals may be feeding at the same time on the kernels of a single sorghum head.

Prepupal Period: When the full grown larva is ready to pupate it selects a favorable place on the food plant, usually among the seeds, and begins to construct a cocoon of white silk, intermixing it with frass or particles of plant material. When completed, the cocoon is securely attached to the surface, grayish or dirty white in color, and measures 7 to 10 mm. in length. On the upper side and slightly before the extreme posterior end a small opening is left in the wall through which the molted skin of the larva is partially pushed out. The cocoons made by larvae reared in close confinement are generally more delicate than those constructed by individuals under field conditions.

After the cocoon has been completed the larva remains inactive. During this quiescent or prepupal period its body contracts gradually so that it is noticeably shorter and thicker. As the pupal case is formed within the old integument, the characteristic green color of the larva turns paler or yellowish, and soon thereafter the final molt occurs. The cast skin gradually moves backward over the tip of the newly formed pupa and is crowded partly through the aperture that has been provided near the posterior extremity of the cocoon. The duration of the prepupal period, as observed in cage rearings, is subject to some variation. The extremes recorded ranged from less than 1 to slightly over 3 days.

Pupation

Normally the sorghum webworm pupates from the fifth larval instar within a cocoon prepared for the purpose, although some exceptions were noted among individuals reared in close confinement. In the field, pupation occurs upon the food plant. Confined larvae, however, usually left the food that was supplied and attached their cocoons to the cages mainly along the angle between the top and sides. In cages, also, the larvae sometimes

pupated without preparing any cocoons, but the mortality among such individuals was unusually high. The abnormal procedure of pupating in the open was probably the result of unfavorable technique in handling the worms at some especially critical period of their development.

The newly transformed pupa is rather soft and light or pale yellowish in color. As the pupal case hardens, the color gradually deepens to dark reddish brown. When disturbed the pupa exhibits some activity which is characterized by a wriggling or twisting movement of the terminal segments. The time required for transformation and emergence of the adult is discussed in the following paragraphs.

Pupal Period: From May to September 1932 and during the same period in 1934, a total of 523 pupae, including five generations, was caged for observation on the duration of this developmental period. A summary of the records secured in these studies is given in Table 6. The average

Table 6. Duration of pupal period of the Sorghum webworm

Pupated		Adult emerged		Lot pupal days	Weighted average pupal period days	Average mean temperature
Lot number	Date	Date	Number adults			
1	May 25, 1932	June 3–4, 1932	4	37	9.25	80.3
2	May 26,	June 4–5,	4	38	9.50	79.9
3	May 30,	June 6,	16	112	7.00	79.1
4	May 31,	June 6,	6	36	6.00	78.8
5	June 26,	July 1–3,	5	27	5.40	83.4
6	June 27,	July 2–3,	13	74	5.69	83.2
7	June 28,	July 4–5,	10	66	6.60	84.0
8	June 29,	July 5–6,	18	111	6.16	84.2
9	June 30,	July 6,	6	36	6.00	84.1
10	July 1,	July 7,	5	30	6.00	84.6
11	July 19,	July 24–25,	13	71	5.46	85.1
12	July 20,	July 25–27,	26	147	5.65	86.1
13	July 21,	July 26–27,	4	22	5.50	86.1
14	July 22,	July 27–29,	7	42	6.00	86.7
15	July 25,	July 30–August 1,	3	18	6.00	86.8
16	Aug. 2,	August 9,	4	28	7.00	88.7
17	Aug. 3,	August 9–10,	9	60	6.66	88.1
18	Aug. 4,	August 10–11,	5	33	6.60	87.7
19	Aug. 26,	September 2,	8	56	7.00	85.3
20	Aug. 27,	September 2–5,	22	150	6.81	84.0
21	Aug. 28,	September 3–6,	17	110	6.47	83.7
22	Aug. 29,	September 4–6,	3	20	6.66	83.7
23	May 17, 1934	May 22–25, 1934	25	148	5.92	77.5
24	May 18,	May 23–26,	8	53	6.62	77.5
25	May 23,	May 28–June 2,	3	22	7.33	76.6
26	May 31,	June 6–7,	11	73	6.63	81.5
27	June 1,	June 7,	4	24	6.00	81.9
28	June 11,	June 18,	3	21	7.00	86.5
29	June 13,	June 19–20,	3	19	6.33	87.9
30	June 15,	June 19–20,	6	29	4.83	88.6
31	June 16,	June 20–22,	12	57	4.75	88.4
32	June 17,	June 21–23,	8	38	4.75	87.9
33	June 18,	June 22–24,	5	25	5.00	87.3
34	June 20,	June 25–28,	4	26	6.50	85.1
35	June 23,	June 29–July 1,	3	21	7.00	84.5
36	July 5,	July 10–13,	18	117	6.50	86.3
37	July 6,	July 11–13,	36	230	6.38	86.2
38	July 7,	July 13–14,	17	115	6.76	86.0
39	July 8,	July 12–15,	26	149	5.73	85.9
40	July 9,	July 15–16,	6	41	6.83	85.7
41	July 11,	July 16–17,	3	17	5.66	86.5
42	Aug. 4,	August 10,	23	138	6.00	86.3
43	Aug. 5,	August 11–12,	34	222	6.52	85.7
44	Aug. 6,	August 12–13,	6	37	6.16	85.9
45	Aug. 7,	August 13,	3	18	6.00	86.0
46	Aug. 10,	August 16–17,	9	55	6.11	86.4
47	Aug. 23,	August 28–30,	5	33	6.60	85.9
48	Aug. 24,	August 30–31,	13	82	6.30	85.5
49	Aug. 25,	August 30–Sept. 2	12	76	6.33	85.5
50	Aug. 26,	September 1–2,	9	59	6.55	85.1

mean temperature which prevailed from the date of adult emergence is also indicated for each lot of pupae under observation. These records indicate that the time required for transformation to the adult is subject to considerable variation. This was true even among individuals which pupated on the same day and developed under like environmental conditions. Obviously other factors besides temperature also influence the rate at which transformation takes place. The data recorded in Table 6 indicate that the duration of the pupal period may vary from 4.75 to 9.25 days; the average, based on all observations included, is 6.33 days. Both sexes required about the same length of time for transformation during the pupal stage.

Total Developmental Period

A summary of the various developmental stages of the sorghum webworm is presented in Table 7. It will be observed that wide variations occurred in the duration of each successive stage from egg to pupa, inclusive. The minimum periods noted indicate, theoretically at least, that total development may occur within 16 days, but no individual was observed to develop from egg to adult in this minimum period. Under average conditions a generation of the sorghum webworm is produced in approximately 24 days. The time required in the separate developmental stages is distributed approximately as follows: 4.2 days for incubation of the egg; 13.4 days for larval development; and 6.3 days for transformation in the pupal stage.

Table 7. Summary of developmental stages of the sorghum webworm

	Number of individuals observed	Maximum period days	Minimum period days	Average period days
Egg	743	6	2	4.18
First instar	307	4	2	2.60
Second instar	282	5	2	2.60
Third instar	278	5	2	2.41
Fourth instar	274	6	2	2.67
Fifth instar	182	7	2	3.09
Pupa	523	9	4	6.33
Total	.....	.....	.....	23.88

Supernumerary 6th and 7th instars omitted.

Emergence of Adults

When transformation has been completed and the moth is about to emerge, the pupal case splits along the dorsomedian line from the base of the cephalic extremity to well beyond the middle of the pronotum, and also on each side along the sutures which define the outer margins of the wing pads. This more or less T-shaped split permits the moth to make

its exit from the pupal case. The cocoon enclosing the latter is readily penetrated by the moth, but the irregularly shaped exit holes thus made indicate no special structural provision for emergence of the adult.

Immediately after emergence the wings are small and distorted, but soon begin to unfold and flatten out. During this process the moth normally remains rather inactive but may crawl about to some extent, especially if disturbed. When the wings are fully expanded they come to rest over the body in a horizontal position so that the moth assumes a characteristic triangular shape as illustrated in Figure 2. At this time the wings are still soft and unfit for normal flight but they usually become fully hardened within an hour or two.

In cages all moths emerged from the pupal cases after five o'clock in the afternoon and before seven-thirty o'clock in the morning. Since emergence invariably occurred over night, it was not frequently observed. The time required for the entire process of emergence was not definitely determined. When the pupal case is removed from the cocoon the moth may complete emergence within ten minutes, and usually an additional period of ten to twenty minutes elapses before wings become fully expanded.

Habits and Activities of Adults

Sorghum webworm moths are nocturnal in habit or are more active at night. After dusk in the field they may be commonly observed in making short, rapid, or dart-like flights from plant to plant. During the day time they are much less active and usually remain concealed or rest inconspicuously on the undersides of the leaves, among the kernels of grain, or in other situations where they are least likely to be disturbed. It is a common habit of the moths when alighting on the upper surface of a leaf to crawl immediately to the under side. In favorable locations they may remain motionless for periods of a half day or longer, and during these quiescent periods the antennae and legs are held closely appressed to the body.

In cages, also, moths were generally inactive during the day time, resting for long periods in places least exposed to direct light. The favored resting position on the sides of the cages appeared to be with the head directed downward. In close confinement the moths fed readily on either sweetened or unsweetened water supplied in moistened cotton or blotting paper. Occasionally they also were observed on the surface of wet soil in large cages, and it appears likely that moisture may be secured from a similar source in the field. No individuals were observed to visit blooms for nectar. The rather poorly developed or short tongue restricts the moths to food sources that are easily accessible.

Longevity of Adults

The moths are relatively long lived. In close confinement the maximum longevity noted was 23 days, but under field conditions the normal life period is probably more protracted.

Out of a total of 50 moths confined by pairs in 20 x 150 mm. glass cylinder

cages with access to unsweetened water, 28 died within 10 days. Of the remaining moths, 21 lived from 11 to 20 days, while one individual lived for 23 days. The longevity records secured for all moths kept under observation are listed in Table 8. According to these data the average

Table 8. Longevity of sorghum webworm moths

Pair number	Male			Female		
	Date emerged	Date died	Longevity days	Date emerged	Date died	Longevity days
1	April 13	April 29	16	April 13	April 19	6
2	April 17	May 10	23	April 17	May 7	20
3	April 19	April 27	8	April 19	May 1	12
4	April 19	May 1	12	April 19	May 29	10
5	April 19	May 2	13	April 19	April 28	9
6	April 20	April 26	6	April 20	May 5	15
7	April 23	May 1	8	April 23	May 10	17
8	April 26	May 12	16	April 26	May 9	13
9	April 26	May 6	10	April 26	May 10	14
10	April 27	May 12	15	April 27	May 14	17
11	May 2	May 14	12	May 2	May 12	10
12	May 3	May 10	7	May 3	May 13	10
13	May 5	May 20	15	May 5	May 18	13
14	May 5	May 18	13	May 5	May 18	13
15	May 5	May 23	18	May 5	May 22	17
16	May 6	May 21	15	May 6	May 21	15
17	May 13	May 19	6	May 13	May 21	8
18	May 16	May 24	8	May 16	May 23	7
19	May 17	May 21	4	May 17	May 23	6
20	May 18	May 25	7	May 18	May 24	6
21	July 5	July 7	2	July 5	July 12	7
22	July 5	July 10	5	July 5	July 12	7
23	July 19	July 22	3	July 19	July 25	6
24	July 25	July 29	4	July 25	Aug. 1	7
25	July 25	July 30	5	July 25	Aug. 2	8
Average	.....	.....	10.04	.....	.....	10.92

life of the female is slightly longer than that of the male and extends over a period of less than 11 days for either sex.

The longevity records of 20 moths confined in cages without access to water ranged from 2 to 8 days and averaged approximately 4.5 days. These observations seemingly indicate that a readily accessible source of moisture is a very essential requirement of the moths.

Flight and Dissemination

Although sorghum webworm moths have not been observed to make extended flights during the day time, there is evidence to indicate that they are fairly strong fliers and capable of spreading readily by flight from field to field throughout the summer. Locally, during seasons when climatic conditions are favorable for rapid multiplication of the insect, few crops of developing grain sorghums escape invasion as the season advances. During July and August 1935, three small plats of hegari from one to three miles away from any apparent source of infestation were kept under close observation. All of these plats were reached by sorghum webworm moths as evidenced by the presence of eggs and young larvae on the heads of grain during the latter part of August. Further evidence that the moths cover considerable distance by flight is indicated by repeated

collections of larvae from corn silks in locations ranging up to three miles from the nearest field of grain sorghum.

While adults generally remain quiescent during the daytime they resume normal activities after dusk, and dispersal or dissemination by flight seemingly occurs at this time. The occurrence of rather evenly distributed infestations within large fields indicates considerable travel from plant to plant by ovipositing moths. There are no definite seasonal periods of migration, but the flight activities of the moths extend throughout the growing season.

CONTROL AND PREVENTION

Natural Control

Climatic Conditions: Among the natural factors affecting the normal activities of the sorghum webworm, climatic conditions are of greatest importance in the prevention or control of injurious infestations. In fact, the most commercially important grain sorghum producing region, located in Northwest Texas, has remained uninvaded mainly because the seasonal rainfall is too small to meet the minimum moisture requirements for permanent establishment of the pest.

Even in the more humid sections of the State where the insect is generally distributed, outbreaks of injurious proportions are characteristically periodic. Evidence accumulated in this connection indicates that the extent to which populations of the sorghum webworm develop during any season is closely correlated with prevailing weather conditions, and especially the amount of rainfall. During wet seasons when temperatures are usually moderate, multiplication proceeds at a maximum rate and extensive damage to grain sorghum crops is likely to result. These were precisely the conditions which prevailed in local sections of the State in 1935 and 1936, and extensive losses were incurred by growers during both seasons. On the other hand, the occurrence of prolonged spells of hot, dry weather, as experienced in 1934, proved very effective as a natural control of the insect throughout the season.

The minimum winter temperatures recorded at College Station during the seasons 1932-33 to 1935-36, inclusive, and including a minimum of 16 degrees F. in February 1936, did not prove effective as a factor in natural control.

Parasites: The developmental stages of the sorghum webworm are attacked by several species of insect parasites of which only one appears of appreciable economic importance in local sections of the State. The parasites reared include four species of Hymenoptera determined by specialists of the U. S. Bureau of Entomology and Plant Quarantine as follows: *Apanteles sorghiellae* Muesebeck; *Meteorus* ? *hyphantriae* Riley; *Cremastus minor* Cushman; and *Spilochalcis delira* Cresson. In addition to these forms *Calolaccus aeneviridis* Girault and *Harismenus microgaster* Ashmead were also reared from mass collections of sorghum webworms, but these are not definitely known as primary parasites of the present host.

In Missouri, Haseman (10) recorded *Trichogramma minutum* Riley attacking *Celama sorghiella* eggs, but this species was not observed in these studies.

Rearing records indicate that *Apanteles sorghiellae* Muesebeck is the most common and important parasite of the sorghum webworm. The species oviposits within the body of the host, where the parasitic larvae complete their development. The larvae emerge from the host when mature and pupate in clusters upon its body, each individual enclosing itself in a small white cocoon (Figure 2). Seven to ten days are required for pupal development and emergence of the adult parasite. Host larvae in all instars after the second were found subject to attack. After parasitism has been effected the host remains active and continues to feed until shortly before the parasitic larvae have attained full growth and emerge to pupate. Soon after this the sorghum webworm dies, and usually six or eight parasites develop at the expense of one host individual.

This parasite appears most numerous during the latter half of the growing season. Records taken in October 1935 indicate a maximum parasitism of 38 per cent. Overwintering sorghum webworms collected in lots from local infested field and kept under observation during the dormant season 1935-36 showed parasitism by this species ranging from less than 1 to 15 per cent. The parasites continued to emerge throughout the winter up to April of the following spring.

Two of the parasites listed above, viz., *Spilochalcis delira* and *Cremastus minor*, attack the pupae of the sorghum webworm, but neither species was found in sufficient numbers to be considered of much value in checking the development of injurious infestations. Another unimportant natural enemy of the sorghum webworm is represented by a single specimen of parasitic fly belonging to the Tachinid genus *Achaetoneura*. The rearing was made by J. N. Roney at McKinney, Texas.

No important predacious enemies of *Celama sorghiella* larvae were noted. However, spiders were occasionally observed capturing the moths, and ants destroy the eggs to a limited extent. None of these seems important as a factor in natural control.

Cultural Methods

The use of insecticides for control of the sorghum webworm is not practical, and the chief combative measures depend on crop management. A thorough preparation of the seed bed and the use of an adapted variety of pure strain seed properly spaced to insure a rapid and uniform development of the crop are good farming practices to be observed at all times. But in addition to these, particularly in sections of the State where the insect is likely to become a limiting factor to crop production, a thorough clean-up of crop remnants after harvest and timely planting are the most effective measures to be utilized in reducing crop losses.

Clean-up Practices: It has been determined that the sorghum webworm always passes the winter in or on its food plant. This peculiar habit

may be utilized to a good advantage in preventing successful hibernation of the insect by a prompt disposal of the crop residue, which constitutes a potential source of subsequent crop infestations. Based on experiments conducted at College Station, it may be stated that plowing under the crop residue to a depth of three or four inches, if thoroughly done, will destroy the overwintering worms. To be most effective, this should be done during the late fall or early part of the winter. Growers who prefer may destroy the crop remnants by burning, but stubbles, which are definitely known to harbor the overwintering worms, cannot be satisfactorily disposed of in this manner and should always be plowed under. When crops are harvested for forage, most of the worms are removed from the field in the stalks and all remnants of the latter left in feed lots should likewise be regularly destroyed during the winter months. Since the insect is capable of subsisting on Johnson grass, all areas of this food plant in the vicinity of grain sorghum fields should be burned over during the dormant season.

Time of Planting: Invariably crops planted to mature late in the growing season suffer the greatest losses from sorghum webworm attack. Although the insect normally appears early in April in the vicinity of College Station, it does not ordinarily multiply rapidly enough to become injurious until the latter half of the season. Consequently, early planting is an effective combative measure. Records taken in local fields during five consecutive seasons ending in 1936 indicate that crops timed to mature prior to the middle of July suffered the least injury. Even during the wet seasons of 1935 and 1936, which were favorable for the development of sorghum webworm infestations, little damage occurred to grain which was past the soft attractive stage by July 1. On the other hand, late planted crops which reached the milk and dough stage in August and September during the same seasons showed losses ranging upwards of 70 per cent of the grain.

Recommendations

Plow under stubbles and all other crop remnants during the fall or early winter and burn over all Johnson grass areas in the vicinity of grain sorghum fields to reduce the overwintering population of worms.

Infested crops harvested for forage should be fed before spring and the unconsumed stalks destroyed before pupation and emergence of the sorghum webworm begins.

Plant early to avoid extensive injury. Crops timed to mature by July 1 throughout Central Texas are invariably damaged the least.

Use improved or pure strain seed and plant only one variety in a field. This insures the most uniform development of the crop and decreases the period over which it remains attractive as food for the insect.

Infested crops harvested for silage may be fed without any apparent injurious effect to livestock.

GENERAL SUMMARY

The sorghum webworm, *Celama sorghiella* Riley, is frequently responsible for severe damage to grain sorghum crops. It was first recorded in 1882 from Alabama and has since been reported from most South Atlantic and Gulf Coast States, and is known to range northward to Illinois and Nebraska.

Injury is caused by the larvae which attack and destroy the seed. The heaviest crop losses have occurred in Texas, Kansas, Arkansas, and Missouri. In Texas the insect has proved most troublesome in regions where the annual rainfall averages 30 inches or more, but outbreaks are periodic and most likely to occur during seasons characterized by prolonged spells of rainy weather.

The insect passes the winter in the mature larval stage on or in the food plant. Pupation of the overwintering worms begins in March, and normally the moths start emerging about April 1. Oviposition begins shortly thereafter, and is continued throughout the growing season. The eggs, laid singly, are firmly attached to the plant with a cement-like substance. The incubation period averages 3 or 4 days in mid-season, and 5 or 6 days in the early or late parts of the season. Larvae may molt four to seven times, but normally there are five developmental instars. Based on the mean duration of the five normal instars, the time required for larval development was about 13.4 days. Pupation occurs within a cocoon, which is spun by the larva on the food plant. The time required for pupal development ranges from about 5 to 9 days and averages slightly less than 6.5 days. The moths are relatively long lived, more active over night, and for this reason not commonly observed in the field. In close confinement the maximum number of eggs laid was 169, but dissections indicate that upwards of 200 eggs per female may be laid under field conditions. Six complete generations and a partial seventh may develop during a single season. The overwintering brood includes larvae of the last two generations.

Control of the sorghum webworm by the use of insecticides is not practical, and chief dependence must be placed in cultural measures. Among the latter, thorough clean-up of the crop residue to destroy the overwintering worms, and planting early to mature the crop before injurious infestations occur are perhaps the most important. Although the insect is attacked by four or five different species of parasites, these are not effective in preventing the development of injurious infestations. Dry weather accompanied by high temperatures is the most effective factor in natural control.

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