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BIONOMICS OF SORGHUM MIDGE (CONTARINIA SORGHICOLA (COQ.)) IN QUEENSLAND, WITH PARTICULAR REFERENCE TO DIAPAUSE

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SUMMARY

During 1950-1957 investigations of sorghum midge (*Contarinia sorghicola* (Coq.)) were made with respect to hosts, sorghum varietal susceptibilities, life history and seasonal populations, with particular reference to the factors influencing development from diapause.

All major hosts recorded are members of the genus *Sorghum*. Minor hosts include several native grasses, of which *Dichanthium sericeum* is the most common, but these hosts have no real influence on pest populations in sorghum crops. Differential varietal susceptibilities amongst commercial sorghums are not evident, although preferences in sites for oviposition are shown under certain conditions.

An egg-to-adult life cycle of 16–20 days occurs during late-summer conditions in central Queensland, and 9–12 generations are possible during the season.

Diapause in sorghum midge larvae is facultative and larvae in this state occur within aborted sorghum spikelets in every midge generation, with the percentage entering diapause rapidly increasing toward the end of the season.

The larvae in diapause are particularly resistant to cold and desiccation and this ensures survival through adverse conditions. Under laboratory storage conditions most diapause larvae remain alive after 18 months and a small percentage can live for more than four years.

The optimal period for diapause larvae to become physiologically mature is 7½ months. Following physiological maturity, morphological development soon occurs after exposure to a high relative humidity (98–100 per cent.), with temperatures in the range 16°–32°C. Development is accelerated by prior thorough wetting of the spikelets, and emergences then commence after 13 days. Most rapid and maximum emergences occur at 28°C with 98–100 per cent. relative humidity.

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In the field, sorghum midge appears in numbers after the natural occurrence of similar conditions, i.e. sufficient rainfall to allow free moisture to be present in the soil for a short period and high humidities for the following two weeks, during the warmer months. Such conditions often occur during the period when sorghum crops are flowering. These studies therefore clearly indicated that sorghum planted so as to flower away from the expected wet season has a good chance of escaping serious midge damage. This has since been well demonstrated by field practice.

I. INTRODUCTION

Sorghum midge (*Contarinia sorghicola* (Coq.)) is a pest of developing sorghum grain. Oviposition occurs within the spikelets at flowering and the larvae feed by sucking directly on the developing ovaries. This results in malformed small grains which are sterile and useless. At larval maturity pupation takes place within the aborted spikelets, and adults emerge through the tops of these, leaving the small white pupal cases attached to the tips of the glumes. During the summer months the insect passes through its life cycle in a few weeks; however, it overwinters as fully grown larvae, in diapause, within the aborted spikelets. In Queensland, diapause larvae are found in trash in sorghum fields, in unharvested heads along fence lines and headlands, in trash and refuse of other hosts, and also in large numbers in improperly cleaned stored sorghum seed (Passlow 1958*b*).

Sorghum midge is recorded from most sorghum-growing areas of the world (see Barnes 1956). This suggests that the insect was distributed to many countries and established in them long before modern recording of pests began. Although Coquillet (1898) described and named the species as *Diplosis sorghicola* from material collected in the United States of America, the first record was made four years earlier in Queensland. Tryon (1894) recorded *Diplosis* sp. bred from broom millet in southern Queensland and his description leaves no doubt that the insect dealt with was that now known as *C. sorghicola.* The species *Contarinia caudata* described by Felt (1920) from India appears to differ from *C. sorghicola* in having a larger and somewhat turned-up ovipositor. Such artefacts have been noted frequently in Queensland material of *C. sorghicola*; their occurrence depends on whether specimens have been killed quickly or allowed to die. Hence *C. caudata* may be the same as *C. sorghicola.*

In Queensland, three fairly distinct sorghum crops are grown, namely early, mid and late season. In central Queensland these crops flower respectively in December to early January, late January to early March, and late March to May. Flowering is somewhat earlier for each crop in southern districts. The incidence of *C. sorghicola* damage from season to season and within the above sections of any one season varies, however, from almost nil to near complete loss of crops.

The present investigations, carried out during the period 1950-1957, were initiated primarily to find the reasons for the irregular midge infestations and to determine means of avoiding crop damage. The results of some parts of the work have been published (see Passlow 1958*a*, 1958*b*, 1960). The remaining parts, covered in this paper, include investigation of hosts, sorghum varietal susceptibilities, life history and seasonal occurrence with particular reference to diapause, and the conditions causing the insect to emerge from diapause.

II. GENERAL METHODS

During this study large numbers of aborted sorghum spikelets were examined for the presence and condition of *C. sorghicola* stages, particularly diapause larvae. The standard dissection method evolved was as follows: the outer glume was removed using fine-pointed forceps, the spikelet with exposed palea uppermost then embedded in a pad of firm plasticine on a microscope slide and the dissection for larvae carried out with mounted needles under a × 20 stereoscope microscope. Larvae were considered alive while their body contents were both red and fluid.

In laboratory experiments, temperatures were maintained in thermostatically controlled incubators, the most variable of which was accurate to within 1°C of the required temperature.

During the early part of the work, control of relative humidity was obtained over solutions of potassium hydroxide (Buxton 1931; Buxton and Mellanby 1934; Solomon 1951). In later studies, however, a series of saturated salts (Brimblecombe 1945; O'Brien 1948) were found more suitable.

Humidity chambers were made from 6 in. straight-drawn, flat-bottomed glass tubes of 1¼-in. internal diameter. The chambers (Figure 1) were closed with paraffin-impregnated corks through which were sealed straight-drawn eye-droppers which enabled the air within the chamber to be circulated. The aborted spikelets were held in small buckets suspended on fine copper wires within the chambers. The buckets were straight-drawn, flat-bottomed plastic cylinders 1 in. in length and ¾ in. in diameter. A series of small holes drilled in the bottom and sides of each bucket facilitated air movement within the chamber.

During some of the laboratory studies of diapause, aborted spikelets were stored under room conditions. At Rockhampton mean maximum and minimum daily room temperatures were approximately 25°C and 11°C respectively in winter and 33°C and 22°C in summer. Mean monthly humidity was approximately 70 per cent. throughout the year. Both temperatures and humidities were somewhat lower at Toowoomba, where the early laboratory work was conducted.

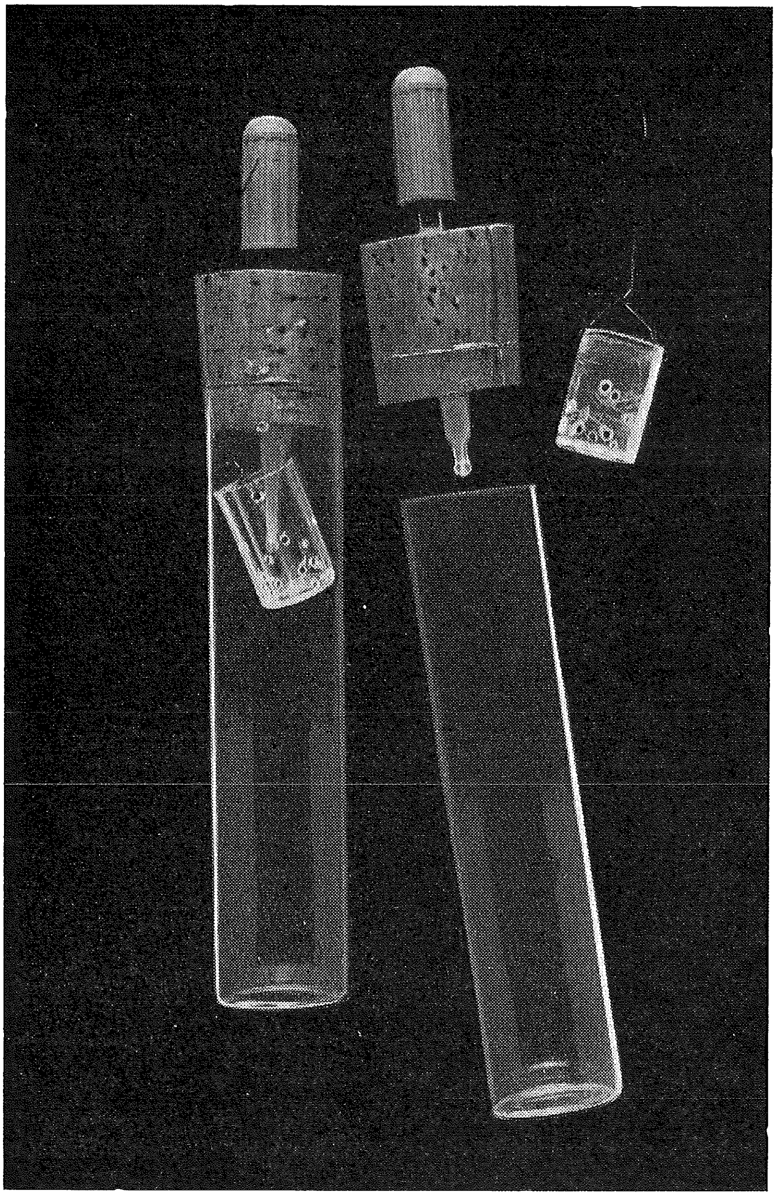

Fig. 1.—Humidity chambers used in temperature-humidity investigations.

III. HOST PLANTS

C. sorghicola is known to breed in all cultivated species of the *Sorghum* genus. Most authors have considered the pest specific to that genus. However, in the United States of America, Dean (1911) and Walter (1941) recorded small numbers from *Triodia flava* (L.) Hitchc., and Dean (1910, 1911) reported small numbers from *Setaria glauca* (= *S. lutescens* (Weigel) F. T. Hubbard). In Africa, Sutherland (1955) recorded the midge from *Andropogon gayanus* Kunth.

During 1950-1957 in the Darling Downs, Callide, Rockhampton and Central Highlands districts, flowering heads from a large range of species of Gramineae were collected and held in breeding jars. Samples other than of the *Sorghum* genus were comprised of a minimum of 100 flower heads.

All species of *Sorghum* yielded large numbers of *C. sorghicola.* Adults of this species were also bred from the following grasses:

Bothriochloa intermedia (R. Br.) A. Camus
Biloela, March 10, 1954: 3 specimens
Malchi, April 1, 1955: 2 specimens

Dichanthium sericeum (R. Br.) A. Camus
Mt. Tyson, February 3, 1953: 2 specimens
Brookstead, February 4, 1953: 9 specimens
Biloela, March 10, 1954: 10 specimens
Biloela, January 12, 1955: 36 specimens
Rockhampton, March 2, 1955: 7 specimens
Malchi, April 1, 1955: 6 specimens

Eriochloa procera (Retz.) C. E. Hubbard
Biloela, October 27, 1954: 2 specimens

Eriochloa pseudo-acrotricha (Stapf ex Thell.) C. E. Hubbard ex S. T. Blake
Biloela, March 10, 1954: 11 specimens

These results indicated that *D. sericeum* is a consistent but minor host of *C. sorghicola* in Queensland. Although it is a major species in most pastures in the sorghum growing areas of the State the percentage of infestation was always low and all breeding records were made when high infestations were present in *Sorghum* in the same locality. *D. sericeum* therefore exerts no appreciable effect on pest populations of *C. sorghicola.*

Although Sutherland (1955) recorded *Andropogon gayanus* as a host of *C. sorghicola* in Africa, none of the many collections of flowering heads of this species in Queensland yielded any sorghum midge.

All the above minor Queenlsand hosts are botanically closely allied to the *Sorghum* genus and this supports the opinion that *C. sorghicola* is relatively specific to this group of plants.

IV. SORGHUM VARIETAL SUSCEPTIBILITY

Bowden and Neve (1953) reported that a group of sorghum varieties of the "Nunaba" type grown in Gold Coast (Africa) were more resistant to midge attack than the standard varieties because they have long papery glumes which do not open at anthesis and thus make oviposition difficult.

Over the whole period 1950-1957, observations were made on the susceptibility of commercial varieties of sorghum grown in Queensland and attention was given particularly to the Nunaba type during the autumn of 1956. Flowering heads were collected in May and held in breeding jars. Emergences of midge and its parasite *Eupelmus australiensis* Gir. were recorded and larvae remaining in diapause were assessed by dissection of 200 random aborted spikelets two months after field collection. The results are summarized in Table 1.

TABLE 1

C. sorghicola AND *E. australiensis* NUMBERS—" NUNABA " SORGHUM

Collection Date	Number of Heads	Total Adults *C. sorghicola*	Total Adults *E. australiensis*	Diapause *C. sorghicola* in 200 spikelets	Estimated *C. sorghicola* per head
May 3	2	22	0	. .	. .
May 10	4	23	0	. .	. .
May 25	11	4,036	6	455	2,640

The later collected material yielded large numbers of midge emergences and diapause larvae and thus there are no suggestions of differential resistance in this variety. Differential damage amongst varieties, however, was recorded on several occasions following either unequal pest populations or an oviposition preference. The semi-open panicle type of sorghum such as Alpha offered less attractive oviposition sites under windy conditions than did the more compact head type such as Caprock.

The results showed that sorghums, including Nunaba, are not differentially susceptible to *C. sorghicola* and although oviposition preferences exist these have no influence under the conditions of large-scale commercial production of sorghum in Queensland.

V. LIFE HISTORY

Detailed life-history studies of *C. sorghicola* have been carried out in the United States of America by Walter (1941) and in Africa by Cowland (1936) and Geering (1953), and in Queensland the life history has been discussed by Atherton (1941) and others. The present studies were conducted to obtain accurate information under central Queensland conditions.

The work was commenced at Garnant, near Rockhampton, during April 1955. Oviposition occurred on April 5. During the following three weeks spikelets were sampled and dissected for presence of *C. sorghicola* stages, and the times and numbers of adult emergence were recorded. Data for the periods of duration were as follows:

Egg stage : 2–3 days, mean $2 \cdot 52 \pm 0 \cdot 51$
Larval stage : 10–12 days, mean $11 \cdot 00 \pm 0 \cdot 75$
Pupal stage : 3–5 days, mean $4 \cdot 06 \pm 0 \cdot 34$
Egg to adult : 16–20 days, mean $17 \cdot 31 \pm 0 \cdot 99$

These results were obtained when the average daily maximum temperature in the surface 2 in. of soil, with some vegetative cover, was 32°C and average screen maximum and minimum were 29°C and 18°C respectively. The figures suggest that the minimum of 12 days for development from egg to adult as given by Atherton (1941) would be reached only during periods conducive to the most rapid development through all stages.

VI. DIAPAUSE STUDIES

Diapause as applied to *C. sorghicola* covers a period of arrested morphological development during which physiological changes continue within the insect. Until these changes are completed, morphological development does not recommence.

Several authors have discussed diapause as a state in which the insect carries through adverse conditions. Although Walter (1941) and Geering (1953) indicated that rainfall was necessary for development from diapause to occur, the point was proved by the present author (Passlow 1954), who recorded that emergence in the field has a close correlation with weather conditions and that, in Queensland, the intensity and magnitude of such emergence have a direct relationship to crop damage. The proof of this statement is given later in this paper.

(a) Incidence of Diapause Larvae in Summer Generations

This part of the study was based upon the numbers of diapause larvae from sorghum flowering at different times during the 1955-56 season at Biloela in central Queensland. Dates of anthesis were recorded during December to May and one month after each date sorghum heads were collected. From these, 100 random aborted spikelets were selected and dissected in groups of 10. The numbers of diapause larvae are given in Figure 2.

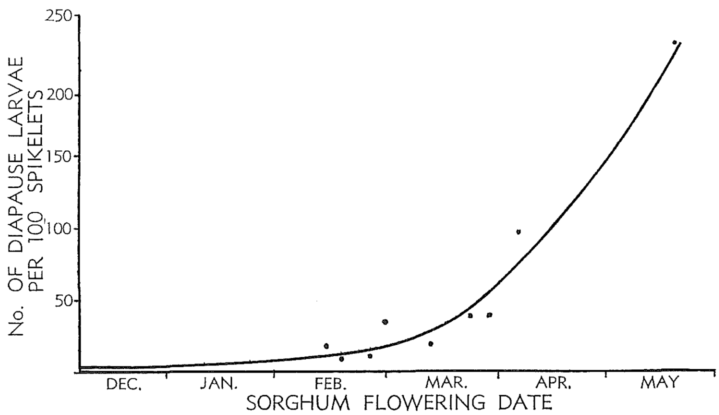

Fig 2.—Incidence of diapause larvae in summer generations.

These data indicated the facultative nature of diapause in *C. sorghicola*. Some individuals entered diapause from most generations, with the percentage entering diapause rising rapidly towards the end of the season. Diapause thus is a normal occurrence in sorghum infestations in the field. It has not been studied in other hosts in Queensland.

(b) Effect of Temperature and Humidity on Diapause Larvae

The effect of exposure to temperatures within the range 0°–55°C and relative humidities from desiccation (over fused calcium chloride) to 100 per cent. were studied in the laboratory at Toowoomba during 1952. Each sample contained a minimum of 200 aborted spikelets and results were assessed as numbers of living diapause larvae in 50 random spikelets per sample. Pretreatment assessments gave a mean 36 diapause larvae per 50 spikelets. Results are summarized in Table 2.

TABLE 2

Diapause Larvae per 50 Aborted Spikelets

Effect of temperatures and relative humidities

Exposure Conditions		Length of Exposure	Living Diapause Larvae at End of Exposure	Living Diapause Larvae (% of pretreatment)
Temperature (°C)	Relative Humidity (%)			
55	100	24 hr	0	0
55	83	24 hr	0	0
55	0	24 hr	0	0
33	100	118 days	1	2·8
33	100	221 days	0	0
33	83	118 days	11	30·6
33	83	221 days	0	0
33	15	118 days	0	0
33	0	30 days	22	61·1
33	0	90 days	0	0
Room	0	30 days	24	66·7
Room	0	90 days	22	61·1
Room	0	302 days	14	39·0
20	100	221 days	no significant	100
20	83	221 days	changes from	100
20	15	221 days	pretreatment	100

Larvae did not survive a high temperature (55°C) irrespective of humidity. At 33°C there was some survival in the shorter periods, but long exposure was fatal irrespective of humidity. Lower temperatures gave some survival over long periods even under dry conditions and at 20°C there was complete survival even at very low humidities.

These data show the value of diapause in enabling the insect to survive prolonged periods of adverse conditions.

(c) Laboratory Emergence of *C. sorghicola* from Diapause

This investigation was carried out at Rockhampton between November 1954 and May 1957. Mature diapause larvae were incubated at all combinations of four temperatures (16, 22, 28 and 32°C), four relative humidities (86, 94, 98 and 100 per cent.) and three pre-incubation wetting rates. Moisture applications were nil, and complete immersion in water for ¼ hr and 2 hr in plastic cylinders 1¾ in. by ¾ in. diam., air bubbles being excluded. Incubation was commenced following surface drying of the aborted spikelets between sheets of blotting paper. Mean percentage moisture contents with standard deviations of unwetted and wetted material based on surface dry weights at incubation were:—

No wetting (air-dry): $12 \cdot 26 \pm 1 \cdot 89$, range $10 \cdot 99$–$14 \cdot 01$
¼-hr wetting : $46 \cdot 13 \pm 1 \cdot 09$, range $44 \cdot 4$–$47 \cdot 9$
2-hr wetting : $53 \cdot 69 \pm 0 \cdot 83$, range $52 \cdot 2$–$55 \cdot 4$

At commencement of incubation and again 8 and 24 hr later the rubber tops of the chambers were given 100 movements to assist in circulating the micro-atmosphere around the spikelets, thus ensuring uniform conditions of relative humidity.

Two samples each containing approximately 40 diapause larvae were incubated for 8 weeks at each combination throughout the experiment, which comprised eight trials. The trials were commenced on November 30, 1954, February 4, April 22 and June 22, 1955, October 9 and December 5, 1956, and January 9 and March 8, 1957. All adult insects developing during incubation were removed three times weekly from the chambers and numbers recorded. Excessive mould growths on and around the spikelets were removed manually as required. All spikelets were dissected at the end of each trial for records of living diapause larvae.

Results are given as percentage of insects which emerged and the number of days of incubation required for mean first emergence (Table 3). Some combinations which gave no emergence are omitted. In all trials emergence was rapid following the first *C. sorghicola* adults being noted. Approximately 80 per cent. of total emergence occurred during the following week.

TABLE 3

PERCENTAGES OF EMERGENCE AND DAYS OF INCUBATION TO FIRST EMERGENCE

Laboratory study

Incubation Conditions		Emergence (%) at:				Period to First Emergence (Days) at:			
Relative Humidity (%)	Pre-incubation Wetting Time (hr)	32°C	28°C	22°C	16°C	32°C	28°C	22°C	16°C
86	2	. .	. .	0·3	. .				
94	¼	. .	0·6	1·0	. .				
94	2	0·3	1·0	2·8	. .				
98	nil	. .	0·6	0·6	. .				
98	¼	1·2	12·5	45·9	4·1		13	23	
98	2	12·0	35·8	61·7	33·7	15	13	20	38
100	nil	4·0	69·4	78·3	23·2	34	22	27	43
100	¼	8·0	77·4	88·6	77·9	20	15	20	35
100	2	14·2	86·4	87·7	72·1	17	14	18	35

These results proved that development from mature diapause larvae to adult insects occurred when material was subjected to temperatures from 16° to 32°C and with relative humidities above 94 per cent. Emergence occurred much sooner when the aborted spikelets containing the diapause material had been wetted thoroughly prior to incubation. Greatest percentage of emergences and minimum incubation periods were recorded at 22° and 28°C respectively with either 98 or 100 per cent. relative humidity.

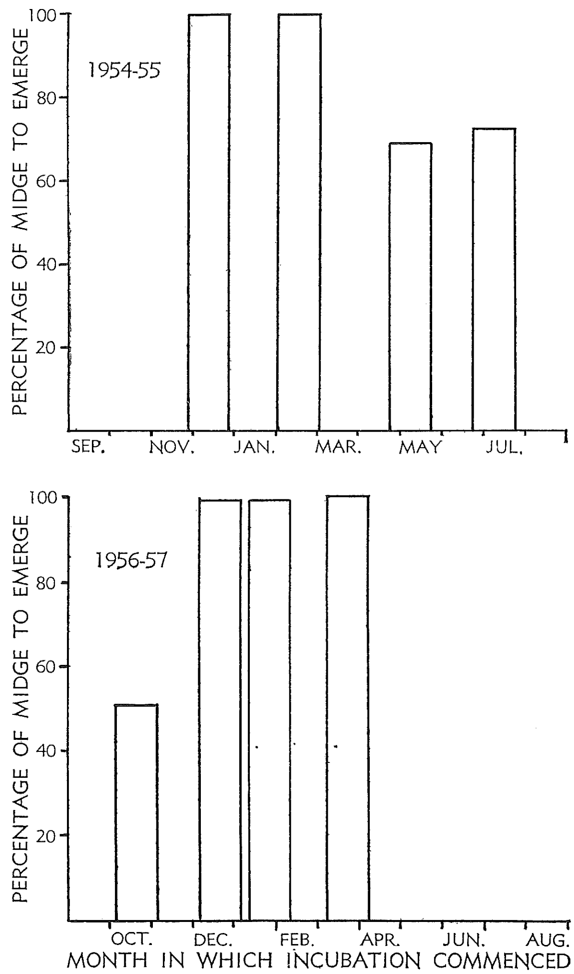

Fig. 3.—Percentages of midge emergence.

Variability was shown for emergences at each set of conditions among the trials, even with wetting—e.g. at 28°C and 100 per cent. relative humidity emergence ranged from 51 to 100 per cent. A definite pattern indicating high summer emergence, however, was noted (see Figure 3). High natural emergences in the field were obtained during the period from November to March, which is the major flowering period for sorghums in central Queensland and the period during which field conditions most suitable for emergence are most likely to occur. A seasonal cycle or periodicity therefore is indicated for *C. sorghicola* emergence from diapause and the insect shows a remarkable adaptation to both host and environment in the field.

(d) Diapause Longevity

A study of the periods for which diapause larvae remain alive when held at room temperature was made at Toowoomba during 1952-53 and continued with the same material at Rockhampton until 1956. A series of approximately 5000 aborted spikelets containing diapause larvae was collected during January 1952 and held in bulk in the one large breeding jar. Regular dissections of 100 random spikelets were carried out over the following four years and numbers of living diapause larvae recorded (Figure 4).

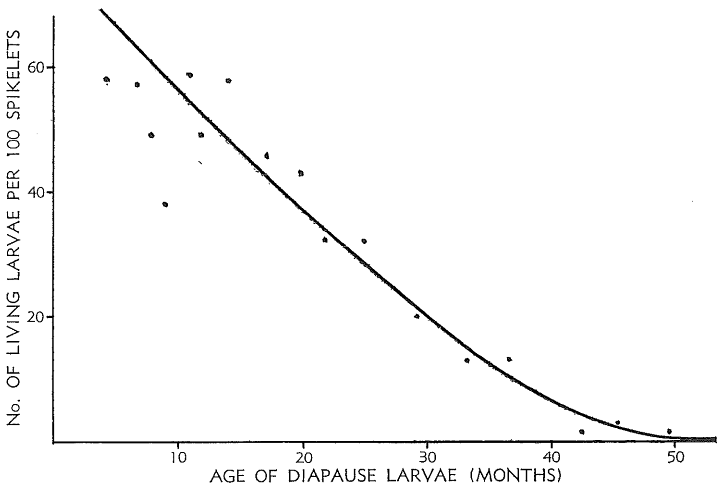

Fig. 4.—Longevity of diapause larvae.

These results showed that under room conditions few diapause larvae died during the first 18 months from the time of field collection and storage, that a reasonable proportion remained alive after three years and that some were living after four years of storage.

(e) Physiological Maturity

Further studies on the time required for diapause larvae to become physiologically mature under room temperatures were made at Rockhampton during 1956. Aborted spikelets were collected from the field during late March following oviposition in late February, and samples were incubated at monthly intervals at 28°C and 100 per cent. relative humidity after prior immersion in water for 15 min. Results were based on the number of days of incubation required before the commencement of emergence (Table 4).

TABLE 4

INCUBATION PERIODS REQUIRED BEFORE EMERGENCE COMMENCED

Diapause longevity

Commencement Date of Incubation	Age of Diapause Larvae at Commencement of Incubation (months)	Period from Commencement of Incubation to Emergence (days)
May 21	3	70
June 25	4	58
July 23	5	46
Aug. 21	6	22
Sept. 17	7	16
Oct. 9	7½	13

Although emergence of adults was obtained from diapause larvae three months old, a very long period of incubation conditions was required. The expected normal period of incubation of 13 days occurred only after a diapause period of 7½ months. These results demonstrated that a long period is necessary for physiological maturation in diapause larvae but once this is complete adult emergence readily occurs under suitably moist conditions. The results further showed that maturation of diapause larvae which have not yet reached physiological maturity can be accelerated by the application of moist conditions.

VII. FIELD POPULATION STUDY

Preliminary trials for the determination of field populations of *C. sorghicola* adults coming from diapause were made at four different sites in 1953-54. This study was then extended to include the continuous collection of data from December 1954 to March 1956 at two of the sites at Malchi near Rockhampton and at a site at Rockhampton.

Population intensities at these three sites were determined from trapping records taken from two heavy brown-paper sticky strips at each site. The strips were each 2 ft long and 1 ft wide, attached to wooden sheets on a frame in the field and treated with a resin-castor oil mixture. The lower edge of the sheets was 9 in. from the ground. Trapping papers were changed weekly and from these *C. sorghicola* and *Eupelmus australiensis* numbers were recorded in the laboratory with the × 20 stereoscope microscope.

For correlation purposes, weekly soil moisture determinations were made for the 0–2-in. zone, soil temperatures were recorded at the 2-in. depth at 9 a.m. and 2 p.m. on the same day each week, and moisture equivalents were determined for soil within the 0–2-in. zone at each site. These data and insect intensities are given in Figures 5, 6 and 7.

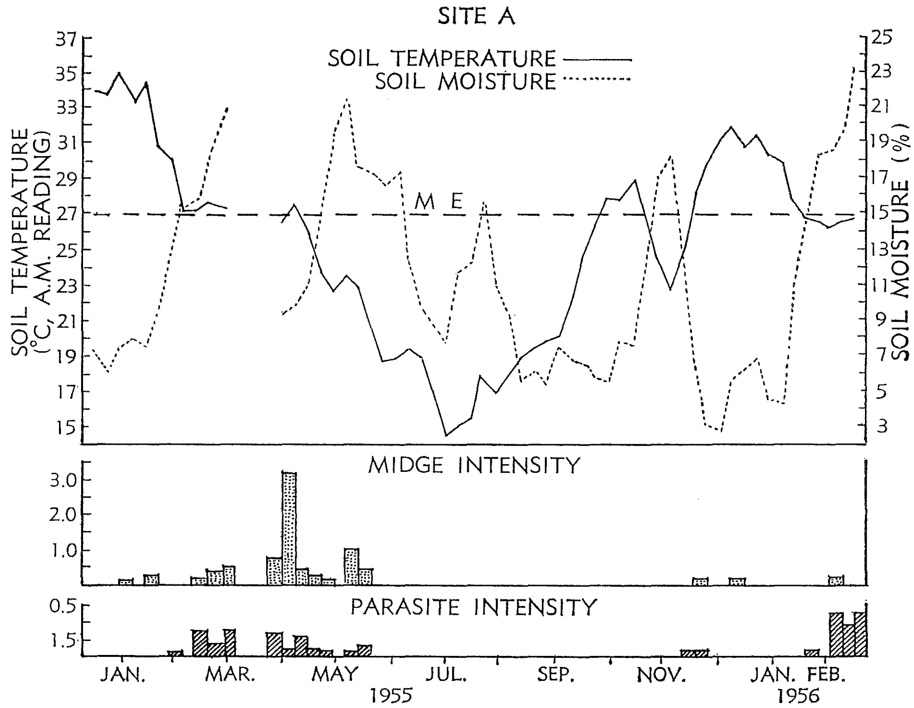

Fig. 5.—Field populations of *C. sorghicola* and *E. australiensis* at Site A. The line marked ME represents moisture equivalent. Midge intensity is given as average number of midges trapped per day, and parasite intensity as average number of parasites trapped per day.

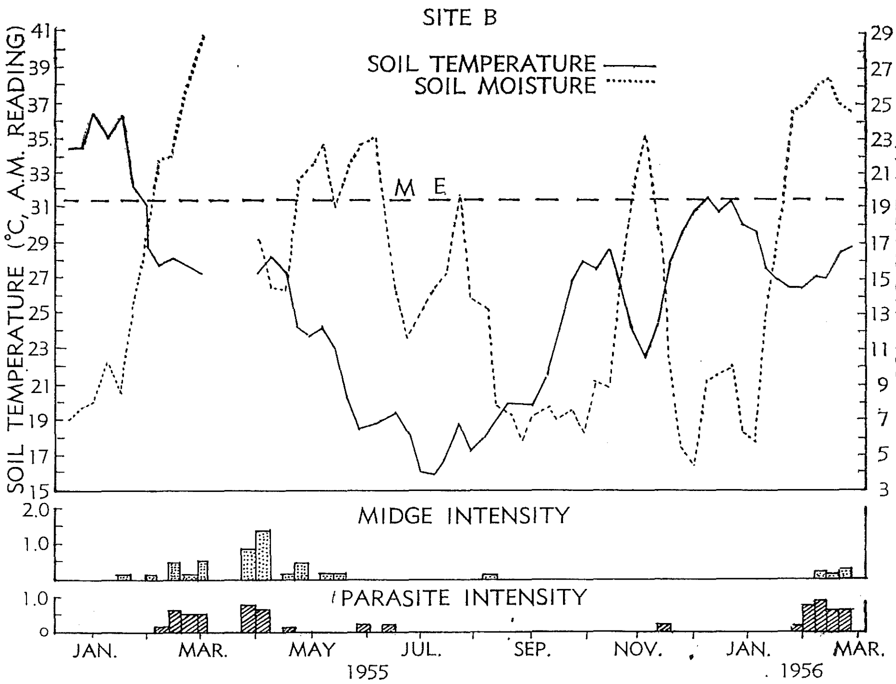

Fig. 6.—Field populations of *C. sorghicola* and *E. australiensis* at Site B. For further explanation, see caption to Fig. 5.

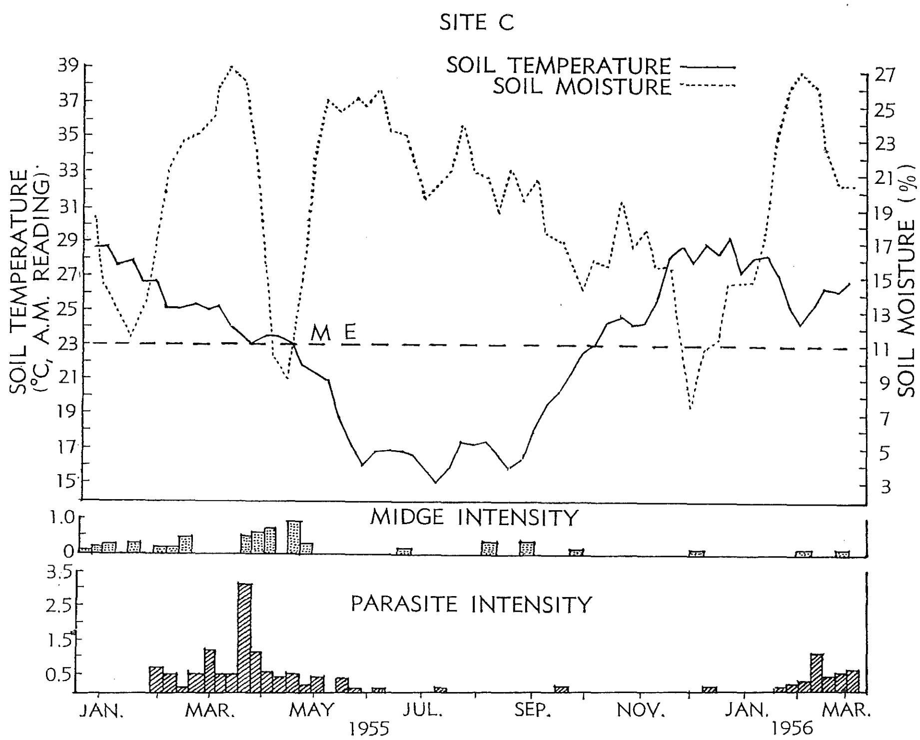

Fig. 7.—Field populations of *C. sorghicola* and *E. australiensis* at Site C. For further explanation, see caption to Fig. 5.

Sorghum was planted on April 10, 1955, in the areas surrounding the two sites at Malchi. With heavy grazing, flowering did not occur and thus *C. sorghicola* generations did not develop in current crops in the area. Any adults appearing must have come from diapause larvae. Midges were taken on the trap strips at both sites under conditions of temperature and soil moisture comparable with the conditions which allowed development from diapause in the laboratory. For example, at one site midges were taken first on February 4, 1955, following wet conditions over the previous fortnight. Soil moisture remained high except for a short period from late March to early April. Adults were trapped regularly until mid May. Soil moisture percentages were low from June to October and no insects were taken in this period. Following the occurrence of high moisture during late October to early November, midges were trapped during November, and again, with high moisture, insects were taken at the end of the experiment in March 1956. Temperatures remained for practical purposes within the 16°–32°C range, which, in the laboratory, allowed development.

The correlation existing between high soil moisture (above moisture equivalent) and *C. sorghicola* numbers points to the importance of thorough wetting of the aborted spikelets containing diapause larvae as a prerequisite for development to adults.

A moisture-adult development correlation was shown for the Rockhampton site but was not so clearly defined, possibly because of different soil types in the area. Sorghum was planted on December 12, 1954, and following the first records of *C. sorghicola* adults, flowering was allowed to occur. Neither harvesting nor grazing was carried out during the work; some flowers, therefore, were present for most of the period. The low numbers trapped and the relative lack of *C. sorghicola* damage during the cold moist months of June to September (15°–17°C and 19–24 per cent. soil moisture) showed that development through to adults did not occur during this period. The occasional insects taken in this period are explained as odd irregular emergences from diapause.

These results demonstrated clearly that weather conditions control emergence from diapause. In addition, the work illustrated a pattern under which high populations of *C. sorghicola* may occur in the field without previous opportunity for seasonal generations. Direct emergence from diapause larvae in crop residues left from earlier seasons, therefore, is the explanation for the numerous occasions, in Queensland, where severe midge damage has occurred in sorghum without pest population build-up within the season. Weather conditions immediately before these occasions have followed the pattern established in this work as suitable for development from diapause, namely continuous warm and moist conditions for approximately a fortnight.

VIII. PARASITE ACTIVITY

During both the laboratory study of emergence of *C. sorghicola* from diapause and the field population studies the parasite *E. australiensis* was encountered.

In the laboratory emergence studies, *E. australiensis* adults were bred at 16, 22, 28 and 32°C, the majority, however, being obtained at 22 and 28°. Unlike the sorghum midge, these insects were taken from material incubated at all four relative humidities used, namely 100, 98, 94 and 86 per cent. No suggestion of arrested development in *E. australiensis* larvae was obtained, illustrating that the parasite apparently does not have a true diapause.

In the field studies, adults of *E. australiensis* were trapped over a somewhat wider range of conditions than those of *C. sorghicola* (see Figures 5–7). The data therefore showed that the parasite is not closely adapted to the host and this supports the conclusion drawn by Passlow (1958*a*) that parasitism by *E. australiensis* has little economic significance.

IX. BIOLOGICAL COMPARISONS

During laboratory investigations some attention was given to oviposition potential and sex ratios in adults from diapause and from summer generation material. Dissections to determine egg capacity were made with 100 females from normal generation material taken at Bongeen during January 1953 and from specimens emerging after diapause from material collected at Biloela during February 1953.

Mean eggs per female were:
Summer generation . . . . . . 95·3 ± 2·50.
Ex diapause . . . . 67·1 ± 2·50.

These results indicated a considerable reduction in oviposition potential in females from diapause. Sex ratios were determined from all *C. sorghicola* bred from a group of sorghum heads during 1955 and 1956 and from specimens emerging from diapause during 1954 and 1956 (Table 5). A variation is shown for the percentages of females from different summer generations and from diapause material, with a lesser percentage of females from the diapause material.

TABLE 5

TOTAL *C. sorghicola* AND PERCENTAGE FEMALES

—		Total Insects	Females (%)
Summer generations	1955	441	57·8
	1956	7,296	62·7
Ex diapause	1954	1,367	56·3
	1956	1,534	47·6

X. GENERAL DISCUSSION AND CONCLUSIONS

These studies have shown that the life cycle of *C. sorghicola* during late summer in central Queensland may be completed in a period of 16–20 days. A number of generations therefore can occur in a single sorghum crop and 9–12 generations are possible during a complete sorghum season. Given a continuity of host flowering material each season, the insect could be a serious pest every year. For agronomic reasons such a continuity of flowering rarely occurs. Summer increase in numbers, therefore, is relatively unimportant except when the initial infestation in well-grown, evenly flowering crops is high. Such initial high infestations do occur in Queensland and the data presented clearly show that they arise directly from development of diapause material.

Diapause in *C. sorghicola* is shown to be facultative, with some individuals from every generation entering this state. The percentage entry to diapause increases sharply towards the end of the season.

Adult development from diapause material occurs only after a period of physiological development within the individuals is complete. The normal period is 7½ months in the laboratory and it is significant that the conditions which then impel morphological development from diapause cause acceleration in the prerequisite physiological development.

In the laboratory, morphological development occurs following the application of a high relative humidity (98–100 per cent.) at temperatures from 16° to 32°C. Development is accelerated by prior wetting of the aborted spikelets and the optimum temperature range is 22°–28°C, with emergence commencing after 13 days of incubation.

Field populations, in the absence of suitable host material, readily develop from existing diapause material following the natural occurrence of similar warm and wet conditions.

The data obtained show that *C. sorghicola* has a remarkable adaptation to both host and environment. In diapause the insect can exist through prolonged periods of drought or cold when suitable oviposition sites would be unavailable. It is evident that the natural conditions which initiate development to adults are similar to those which force growing sorghums into flower production and thus flowering and emergence from diapause occur together.

The facultative nature of diapause, with some individuals entering diapause from each generation, ensures survival of the species irrespective of the availability of oviposition sites late in the season. Further, the period of 7½ months shown under room conditions to be necessary for physiological diapause maturity is greater than the period during which no oviposition sites can be expected for *C. sorghicola* under central Queensland conditions of commercial production of grain sorghum.

Furthermore, in laboratory development trials there is shown a seasonal cycle or periodicity in emergences from diapause. Maximum percentages of emergences from field material occur during November to March, the period in which oviposition sites are most likely to be encountered in the field.

Members of the *Sorghum* genus are shown to be the major hosts, while *Dichanthium sericeum, Bothriochloa intermedia, Eriochloa procera* and *E. pseudo-acrotricha* are recorded as minor hosts. *C. sorghicola* has been considered specific to *Sorghum* and it is significant therefore that the minor hosts recorded are closely allied botanically to the *Sorghum* group. Infestations in these grasses are likely when high populations are present in sorghums in the same area, and because the percentages of spikelet infestations in grasses are always very low the minor hosts are considered to exert no appreciable influence on summer generations.

Differential susceptibility is not apparent among commercial sorghum varieties. Preference for oviposition sites, however, is shown for the compact head rather than the open panicle under windy conditions, and the open-pollinating varieties are preferred to the self-pollinating Nunaba types. Such preferences have no commercial value under large-scale sorghum production methods in Queensland.

The parasite activity encountered shows that *Eupelmus australiensis* does not have a true diapause and that development from larvae in material carrying diapause *C. sorghicola* occurs over a wider range of conditions than those required for midge. The parasite, therefore, is not closely adapted to the host and this supports conclusions drawn earlier by the author (Passlow 1958*a*) that parasitism by *E. australiensis* has little economic significance.

The principal results presented in this paper—namely that diapause is the major factor regulating natural field populations from year to year and that specific conditions allow development of adults from mature diapause material—formed the basis of the recommendation (Passlow 1955) to plant sorghum, when practicable, so that flowering occurs away from the expected periods of wet weather.

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REFERENCES

ATHERTON, D. O. (1941).—The sorghum midge. *Qd Agric. J.* 56:444-9.

BARNES, H. F. (1956).—"Gall Midges of Economic Importance. Vol. VII. Gall Midges of Cereal Crops." (Crosby Lockwood & Son Ltd.: London.)

BOWDEN, J., and NEVE, R. A. (1953).—Sorghum midge and resistant varieties in the Gold Coast. *Nature, Lond.* 172:551.

BRIMBLECOMBE, A. R. (1945).—The biology, economic importance and control of the pine bark weevil, *Aesiotes notabilis* Pasc. *Qd J. Agric. Sci.* 2:1-88.

BUXTON, P. A. (1931).—The measurement and control of atmospheric humidity in relation to entomological problems. *Bull. Ent. Res.* 22:431-77.

BUXTON, P. A., and MELLANBY, K. (1934).—The measurement and control of humidity. *Bull. Ent. Res.* 25:171-5.

COQUILLET, D. W. (1898).—A Cecidomyiid injurious to seeds of sorghum. *Bull. U.S. Bur. Ent.* 18:81-2.

COWLAND, J. W. (1936).—The sorghum midge in the Anglo-Egyptian Sudan. *Ann. Appl. Biol.* 23:110-3.

DEAN, W. H. (1910).—Some notes on the life history and habits of the sorghum midge, (*Contarinia* (*Diplosis*) *sorghicola* Coq.). *J. Econ. Ent.* 3:205-7.

DEAN, W. H. (1911).—The sorghum midge. *Bull. U.S. Bur. Ent.* 85:39-58.

FELT, E. P. (1920).—New Indian gall midges (Diptera). *Mem. Dep. Agric. India, Ent.* 7:1-11.

GEERING, Q. A. (1953).—The sorghum midge, *Contarinia sorghicola* (Coq.), in East Africa. *Bull. Ent. Res.* 44:363-6.

O'BRIEN, F. F. M. (1948).—The control of humidity by saturated salt solutions. *J. Sci. Instrum.* 25:3.

PASSLOW, T. (1954).—The sorghum midge diapause. *Nature, Lond.* 174:656.

PASSLOW, T. (1955).—The sorghum midge. *Qd Agric. J.* 80:251-3.

PASSLOW, T. (1958*a*).—Parasites of sorghum midge, *Contarinia sorghicola* (Coq.), in Queensland. *Qd J. Agric. Sci.* 15:35-6.

PASSLOW, T. (1958*b*).—Destruction of sorghum midge in seed grain. *Qd J. Agric. Sci.* 15:37-8.

PASSLOW, T. (1960).—Insecticidal control of sorghum midge, *Contarinia sorghicola* (Coq.). *Qd J. Agric. Sci.* 17:83-9.

SOLOMON, M. E. (1951).—Control of humidity with potassium hydroxide, sulphuric acid and other salts. *Bull. Ent. Res.* 42:543-4.

SUTHERLAND, J. R. G. (1955).—Gall midges infesting grain sorghums and grasses in Nigeria. *F.A.O. Plant Prot. Bull.* 3:168-9.

TRYON, H. (1894).—The insect enemies of cereals belonging to the genus *Cecidomyia*. *Trans. Nat. Hist. Soc. Qd* 1:21-3.

WALTER, E. V. (1941).—The biology and control of the sorghum midge. Tech. Bull. U.S. Dep. Agric. No. 778.

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