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Off-season survival and seasonal carry-over of the sorghum shootfly, *Atherigona soccata* Rondani (Diptera: Muscidae) in Kenya

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Abstract. Field surveys and laboratory and greenhouse experiments were conducted to study the off-season survival mechanism and seasonal carry-over of the sorghum shootfly, *Atherigona soccata*. In Kenya, active populations of the shootfly survive on tillers produced by sorghum, *Sorghum bicolor*, stubble and wild sorghum, *Sorghum arundinaceum*, during the off-season. No evidence was obtained to support the suggestion that shootflies undergo aestivation-diapause as a mechanism of off-season survival. There was also no indication of a higher reproductive potential for the off-season shootflies which can account for any rapid build-up of the population in the beginning of the sorghum-growing season. Removal and destruction of wild sorghum and sorghum stubble after harvest would disrupt the carry-over of the shootfly and hence may prove to be an effective cultural method of control.

Introduction

Sorghum, *Sorghum bicolor* (L.) Moench, is an important staple crop in many countries of Africa and Asia. A major constraint in the production of grain sorghum in these countries is the great number of insect pests attacking the crop. The sorghum shootfly, *Atherigona soccata* Rondani, which is one of the most important pests of sorghum is widely distributed in the sorghum-growing areas of Africa, the Mediterranean, the Middle East and Asia (Yound and Teetes, 1977). *Atherigona soccata* is a seedling pest, most harmful during the first few weeks after germination (Delobel, 1982). Shootfly infestation produces 'dead-hearts' in the seedling as well as in tillers, resulting in considerable damage to the crop.

Several workers have reported that the shootfly population is extremly low and undetectable during the dry period between cropping seasons (off-season) (Kundu *et al*., 1971), except in places where sorghum is grown continuously under irrigation (Rivanay, 1962). When planted early, sorghum escapes shootfly attack because of the low shootfly population existing at the beginning of the cropping season (Davies and Jowett, 1966). However, in China, damage caused by the first generation of the shootfly was the heaviest and early sown sorghum suffered serious damage (Shiang-Lin *et al*., 1981).

The mechanism of off-season survival and seasonal carry-over of the shootfly is not yet well understood. Except for a few reports of the insect surviving the off-season on wild hosts (Starks, 1970; Granados, 1972; Davies and Seshu Reddy, 1981; Delobel and Unnithan, 1981) and on tillers produced by sorghum stubble after harvest (Delobel and Unnithan, 1981), it is still a subject of speculation. It has been suggested that *A. soccata* larvae and/or pupae undergo a quiescent period or aestivation-diapause during the off-season, thus surviving until the next crop (Barry, 1972; Clearwater and Othieno, 1977; Ogwaro, 1979). Rain-induced termination of diapause (Clearwater and Othieno, 1977; Ogwaro, 1979) together with the high reproductive potential of the off-season shootflies have been suggested as responsible for the rapid build-up of the shootfly population early in the cropping season. We have conducted field surveys and laboratory and greenhouse experiments to study the off-season sorghum shootfly population, existence of any aestivation-diapause as an off-season survival mechanism, and the reproductive potential of the off-season shootflies. The results of these studies are presented here.

Materials and methods

Survey of off-season sorghum shootfly population

Surveys were conducted to determine the off-season shootfly egg and larval population in four different farmers' fields located about 1, 3, 12 and 20 km, respectively, from the ICIPE Mbita Point Field Station in Mbita Division of South Nyanza District in Western Kenya. These fields are in the midst of typical sorghum-growing area, with an annual rainfall of less than 900 mm. Here sorghum is widely grown once a year during the long-rain season (February/March to July/August). During the years when the surveys were carried out, in all the four fields surveyed as well as in the surrounding areas, sorghum was ratooned at harvest in late July/early August, and the land was not ploughed until the following December/January. There were occasional rains during the off-season and the sorghum stubbles produced tillers. Surveys, starting 2–3 weeks after harvest, were conducted during August 1979 to January 1980 in fields 1 and 2, August 1980 to January 1981 in field 3 and August to November 1980 in field 4. Fields 1 and 2 were planted with a local variety of sorghum, whereas fields 3 and 4 were planted with Serena, a sorghum variety known to tiller extensively. A total of 200 to 500 tillers from sorghum stubble were collected at random from an area of 0·5 ha in fields 1 and 2 and 0·25 ha

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in fields 3 and 4. Samples of wild sorghum, *Sorghum arundinaceum*, tillers were also collected from field 4 and its immediate surroundings during October to December, 1981. Tillers with unhatched (newly-laid) shootfly eggs and larvae were recorded, and the larval stages determined. Mature larvae were left in sorghum stems until pupation and adult emergence, for identification and fecundity studies. *Atherigona* adult population was monitored at field 1 by using fish-meal baited water pan traps, once a week during the period from August 1979 to July 1980. Rainfall data for this location were also collected during this period.

Aestivation-diapause

The larvae and pupae collected from farmers' fields during the off-season were kept in the laboratory on the same host-plant material to determine whether there was any sign of quiescence or aestivation-diapause. In addition, an experiment was conducted in the greenhouse to determine whether subjecting the host-plant to dry conditions (water-stress) can induce quiescence or diapause in the shootfly. For this, susceptible hybrid sorghum, CSH-1 was planted in 50 × 40 × 10 cm metal trays (20 seedlings/tray) in a greenhouse maintained at $27{\cdot}5 \pm 2{\cdot}5$°C and $60 \pm 15\%$ relative humidity. The seedlings were fertilized once with a small quantity of liquid fertilizer ('Welgro'), and watered on alternate days for up to 15 days after germination. At this stage the seedlings were infested with shootfly eggs by releasing gravid flies over the seedlings, for 8 h, within a cage. Dead hearts produced were counted 4 days later. One set of trays with the infested seedlings was watered on alternate days (wet conditions) until the end of the experiment, while the other set was not watered (dry conditions) until 6 weeks after the appearance of dead hearts. The seedlings subjected to the dry conditions withered and dried gradually after several days. The adults emerging from the infested seedlings were collected daily and the time taken for development from the egg to the adult stage was recorded. The seedlings subjected to the dry conditions were watered 6 weeks after infestation to determine if this would induce adult emergence. At the end of the experiment, i.e. 8 weeks after infestation, the stems and soil were examined to determine whether any larvae or pupae were still present.

Reproductive potential of the off-season shootflies

In order to determine whether off-season shootflies have a higher reproductive potential, we have studied the longevity, preoviposition and oviposition periods, fecundity (eggs/female) and fertility (percentage eggs hatched) of three groups of insects. These were (1) off-season shootflies (from off-season tillers in the farmers' fields), (2) shootflies whose larval and pupal stages were completed in CSH-1 seedlings subjected to dry conditions, and (3) those subjected to wet conditions in the greenhouse. These studies were conducted in the same way as described earlier (Unnithan, 1981).

Results

Off-season shootfly population

Surveys in the farmers' fields in Mbita Division revealed that, during the off-season, active populations of the sorghum shootfly survived on tillers produced by the stubble of cultivated sorghum after harvest, and on the wild sorghum *S. arundinaceum* (Table 1). This off-season population fluctuated greatly within and between different locations.

In August 1979, in field 1, 14% of the tillers on sorghum stubble had unhatched shootfly eggs and about 19% of the tillers contained 3rd instar shootfly larvae (Table 1). Although eggs were not found in September, all the larval stages and adults were present during this period. The larval population continued to be high until the end of September, after which it declined, reaching the lowest number in January 1980 (Table 1). The fluctuation in the egg and larval populations in field 1 more or less followed those of the adults of *A. soccata* caught in fish-meal traps. During August/September adults were caught every week. Between mid-January and the end of February 1980, which was the driest period, no *A. soccata* adults were caught. The adult population gradually increased again on the new sorghum crop planted at the end of February 1980.

In field 2, *A. soccata* egg and larval populations declined drastically beginning September 1979 and remained low throughout the survey period (Table 1). At the end of October and December, none of the tillers had

Table 1. Atherigona soccata *infestation on sorghum stubble during the off-season in farmers' fields*

	Number of tillers sampled															
	Field 1 (1979–80)				Field 2 (1979–80)				Field 3 (1980–81)				Field 4 (1980)			
Month	Mean*	Egg†	1st/2nd†	3rd†	Mean	Egg	1st/2nd	3rd	Mean	Egg	1st/2nd	3rd	Mean	Egg	1st/2nd	3rd
August	200	14·0	0·6	18·9	200	2·8	0	16·0	484	0·8	2·4	7·0	432	3·7	1·0	2·3
September	200	0	17·2	19·9	361	4·3	0·4	0·4	400	2·7	3·3	6·5	408	2·0	2·0	4·3
October	259	1·9	3·6	2·1	241	0	0·2	0·4	288	24·1	5·6	3·5	269	0·5	1·1	5·4
November	253	5·1	2·1	1·5	286	0·5	0·5	0·3	221	20·2	7·2	7·2	231	1·1	3·0	0·9
December	218	3·9	2·7	1·0	213	0	0·5	0	227	4·4	2·9	11·9	—	—	—	—
January	200	0	0	1·0	262	0·2	0	0	200	4·7	5·8	13·0	—	—	—	—

* Mean number of tillers sampled.

† Percentage tillers (mean) with *A. soccata* infestation: egg, 1st and 2nd instar larvae and 3rd instar larvae.

Table 2. Development of sorghum shootfly in CSH-1 seedlings subjected to wet and dry conditions in the greenhouse

	Treatment	
	Wet conditions	Dry conditions
No. of dead hearts	111	100
% Adult emergence	60·36	49
Development time from egg to adult (days)		
Range	22–39	18–33
Mean ± S.E.	26·69 ± 0·59*	23·73 ± 0·52*

* Significantly different from each other ($P < 0{\cdot}001$) (Student's *t*-test).

shootfly eggs. Green tillers were also fewer during this period.

Atherigona soccata egg and larval populations in fields 3 and 4 (Table 1) were relatively higher during the 1980–81 off-season compared with those at fields 1 and 2 during the 1979–80 off-season. The numbers of available sorghum tillers suitable for shootfly growth and development were also higher in fields 3 and 4. In field 3, sorghum tillers with shootfly eggs and larvae fluctuated from 0·8 to 24·1% and from 9·4 to 18·8%, respectively; while in field 4, 1·1–6·5% and 3·4–6·5% of tillers had eggs and larvae, respectively (Table 1). During October to December 1980 wild sorghum in field 4 showed higher shootfly infestation than sorghum stubbles. Egg and larval population on wild sorghum ranged from 0 to 32% (mean 15·2%) and 3 to 31%, (mean 14·5%), respectively. In all four fields sampled the available number of susceptible tillers showed a gradual decrease during October–December.

Aestivation-diapause

Shootfly larvae and pupae collected from the tillers of cultivated and wild sorghum during the off-season completed their development to the adult stage without any significant delay. There was no sign of diapause. When pupae collected from infested shoots in the field during the off-season were kept at 30–35°C and 30–40% relative humidity, they dried up before completing development, indicating that they were not resistant to desiccation and/or high temperature.

Results of greenhouse experiments in which shootfly larval and pupal development took place in CSH-1 seedlings subjected to dry and wet conditions showed that water-stress to host plants did not induce quiescence or prolongation of larval and pupal period. Instead, the time taken for development from hatching to adult emergence was significantly less ($P < 0{\cdot}001$) (Table 2). However, shootfly mortality was higher in plants subjected to water-stress compared with that in control plants (not subjected to water-stress) (Table 2). In the former, 6% of the adults were unable to emerge. At the end of the experimental period no live larvae or pupae were found in the shoots or in the soil.

Reproductive potential of off-season shootflies

There was no significant difference in fecundity among the three groups of flies (see Materials and methods) studied (Table 3). However, longevity and oviposition period of the off-season shootflies were lower than those of the other two groups of flies. Hatchability of the eggs was significantly less for insects from CSH-1 seedlings subjected to wet conditions (Table 3). The results showed no indication that the off-season shootflies had a higher reproductive potential than the flies which were not subjected to environmental stress.

Discussion

Our study of the natural populations in Western Kenya indicates that shootflies remain active throughout the off-season. This is evidenced by the presence of unhatched eggs and the three larval stages of the pest in tillers of cultivated and wild sorghum. The variation in size and distribution pattern of the off-season shootfly egg and larval populations can be primarily attributed to the variation in the availability of suitable host-plants, which, during the off-season, are the tillers produced by sorghum stubbles and wild sorghum. In many parts of Kenya sorghum

Table 3. Longevity, fecundity and fertility of off-season shootflies and shootflies subjected to dry and wet conditions

Group	No. of flies	Mean female longevity (days)*	Mean preoviposition period (days)*	Mean oviposition period (days)*	Eggs/female (geometric mean)†	Percentage eggs hatched‡
1. Off-season shootflies	31	30·4[a]	4·2[a]	17·6[a]	50·9[a] (17–113)	73·4[ab]
2. Shootflies subjected to dry conditions	13	36·8[ab]	3·6[a]	26·8[b]	62·6[a] (20–130)	76·4[a]
3. Shootflies subjected to wet conditions	10	42·3[b]	7·0[a]	29·6[b]	67·1[a] (19–105)	69·8[b]
		($F = 3{\cdot}33$) ($P < 0{\cdot}05$)	($F = 2{\cdot}88$)	($F = 9{\cdot}82$) ($P < 0{\cdot}01$)	($F = 1{\cdot}42$)	($P < 0{\cdot}01$)

In each column means and percentages followed by the same superscript letter are not significantly different from each other, based on
* Duncans multiple range test and † χ^2 test.
‡ Figures in parentheses represent fecundity range.

harvested after the long rain season is cut low and the stubbles are allowed to tiller (Abasa, 1983). The production of susceptible tillers is influenced by rainfall, tillering capacity of the sorghum variety, cattle grazing as well as the population density of the shootfly and other pests such as lepidopterous stem-borers. The amount and pattern of rainfall in the surveyed areas were not much different. In fields 1 and 2, where the off-season population remained very low, the sorghum grown was of an unknown traditional variety which did not tiller as much as Serena did. At these two sites, tillers were regularly eaten by cattle, whereas in fields 3 and 4 grazing was not allowed in the fields. Grazing, in addition to reducing the available number of susceptible tillers, can also cause mortality in the eggs and larvae. This may be one of the reasons for the relatively low population density in fields 1 and 2. The higher tillering capacity of Serena sorghum and the absence of cattle grazing in fields 3 and 4 increased the available number of suitable tillers for shootfly egg-laying, thus favouring the survival of a larger shootfly population.

Another factor which might have negatively affected the shootfly population during the off-season was the lack of food for shootfly adults. Sorghum aphid honeydew is an important natural source of food for shootfly adults (Unnithan and Mathenge, 1983). During the off-season the supply of honeydew was also low due to the absence or decline of aphid population on sorghum stubbles; this was more so in fields 1 and 2. Shiang-Lin *et al.* (1981) also reported a positive correlation between aphid infestation on sorghum and shootfly population.

Our study did not show any indication of the presence of a quiescence or aestivation-diapause at any life-stage of the shootfly. Subjecting the host plants to water-stress under greenhouse conditions failed to induce diapause or prolong the larval or pupal development. Larval mortality and development duration increased when shootflies were allowed to develop in CSH-1 seedlings deprived of both water and fertilizer (Delobel, 1983); but even in this case, there was no sign of diapause. It has been reported that mature shootfly larvae and/or pupae show extended development or diapause during dry periods (Barry, 1972; Clearwater and Othieno, 1977; Ogwaro, 1979; Young, 1981), which might be terminated by rainfall (Ogwaro, 1979). Contrary to the report of Clearwater and Othieno (1977), a careful study of the rainfall pattern and adult population fluctuations in a farmer's field (field 1) during a 1 year period did not show any evidence of a rain-induced synchronous emergence of shootfly adults. If the shootflies undergo aestivation-diapause and if the diapause is terminated by rain, then it is very unlikely that the early-sown sorghum escapes shootfly attack. The observation that early-sown sorghum escapes heavy shootfly infestation (Ogwaro, 1979) provides an indirect evidence that, at least under East African conditions, the shootflies may not exhibit aestivation-diapause.

Rao and Rao (1956) have reported that shootflies did not have any alternate hosts, nor did they enter diapause. Instead, the female flies were reported to 'hide' in the spindles of ratooned sorghum until the next cropping season. This implied that there was some kind of a reproductive diapause. However, we did not notice any sign of a reproductive diapause during this study. Active populations of the shootfly were found throughout the year in Pakistan (Moiz and Naqvi, 1968), Uganda (Taksdal and Baliddawa, 1975) and in Upper Volta (Bonzi, 1981). Our studies also do not show any indication of a higher reproductive potential for off-season shootflies which can account for any rapid build-up of population in the beginning of the sorghum-growing season.

In conclusion, it is evident from the present study that in Kenya, the tillers produced by sorghum stubble after harvest and the wild sorghum, *S. arundinaceum*, facilitate the off-season survival and seasonal carry-over of the shootfly. Shootflies are present throughout the year in the farmers' fields. No evidence was obtained to support the suggestion that shootflies undergo aestivation-diapause as a mechanism of off-season survival. In view of the role of sorghum stubble and wild sorghum in the off-season survival and seasonal carry-over of the shootfly, removal and destruction of these after harvest would disrupt the carry-over of the pest and hence may well prove to be an effective control strategy. As *Sorghum arundinaceum*, found to grow in sorghum fields and around farming areas, does not appear to be a source of fodder for cattle, removal and destruction of this, from farming areas, as well as sorghum stubble late in the off-season may not have a serious effect on fodder supply. However, the feasibility of adopting this as a cultural method of control of the shootfly needs to be investigated.

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