BIOLOGY OF SORGHUM SHOOT FLY, *Atherigona soccata* Rondani (DIPTERA : MUSCIDAE) WITH REFERENCE TO THE PHENOMENON OF ANTIBIOSIS

By

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CERTIFICATE I

This is to certify that this dissertation entitled, "Biology of sorghum shoot fly, Atherigona soccata Rondani (Diptera : Muscidae) with reference to the phenomenon of antibiosis", submitted for the degree of Ph.D., in the subject of Entomology of the Punjab Agricultural University, is a bonafide research work carried out by Mr. Ramesh Chander under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the dissertation entitled, "Biology of sorghum shoot fly, Atherigona soccata Rondani (Diptera : Muscidae) with reference to the phenomenon of antibiosis" submitted by Mr. Ramesh Chander to the Punjab Agricultural University in partial fulfilment of the requirements for the degree of Ph.D., in the subject of Entomology has been approved by the Students Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

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Chapter I

INTRODUCTION

Sorghum shoot fly, Atherigona soccata Rondani (Diptera : Muscidae) is one of the major insect pests of sorghum (Sorghum bicolor (L.) Moench) in all the sorghum growing regions of Asia and Africa. The fly has gained importance in India, Thailand, Israel and African countries after the release of high yielding varieties and hybrids of sorghum.

The damage to the crop is caused by the maggots, which soon after hatching from minute whitish eggs laid on the underside of the leaves, travel downward in between leaf-sheath and axis and cut the growing point, finally producing 'dead heart'. The attack starts soon after the emergence of seedlings and continues for about one month. Very young plants die off, while others produce tillers which mature late or are further attacked to cause multi-tillered dead hearted plants known as 'tussock'.

Shoot fly remains active throughout the year but exhibits two distinct periods of high incidence on early (March-April) and late (August-September) sown crops. The normal kharif (June-July) crop suffers less losses as compared to the rabi (October-November) sown crop.

Different control measures have been suggested for saving sorghum crop from shoot fly attack but none has so far gained popularity with the growers due to high inputs involved in initial cost of insecticides and cumbersome cultural practices (transplanting, heavy seed rate and removal of 'dead hearts'). Single factor approach in insect control is often insufficient. The present strategy of an integrated control system demands the judicious use of non-chemical methods, emphasising the utilization of plant resistance to insects. Since the crop and crop variety is a part of agro-ecosystem, the solution to shoot fly attack may lie in the evolution of suitable resistant cultivars. However, non-preference and antibiosis to some degree, if found in any germplasm could be exploited for achieving success in suppressing shoot fly problem.

It is desirable to study the biology and behaviour of shoot fly for evolving suitable control measures and to determine non-preference and antibiosis phenomena of plant resistance.

The biology and field behaviour of Atherigona soccata has been studied inadequately and very little is known about its activity on different germplasm of sorghum. Considering the importance of shootfly vis-a-vis the cultivation of sorghum, the present investigations were carried out to study the biology of A. soccata with

reference to the possible phenomenon of antibiosis in the promising germplasm. It is hoped that the findings of this study will prove useful to persons interested in both academic and practical problems concerned with sorghum shoot fly and its integrated control programme.

Chapter II

REVIEW OF LITERATURE

Sorghum shoot fly, reported to be a prominent pest of sorghum from Oriental, Ethiopian and Mediterranean regions, was studied and described under different names. The common synonyms of shoot fly are:-

Species of shoot fly	Country/Region	Reference
Atherigona acutipennis Vill.	Africa	Villeneuve (1921) (quoted by Deeming, 1971).
A. indica Malloch	India	Malloch (1923 & 1925), Ramachandra Rao (1924) and many others.
	Tanganyika	Harris (1934) and Swaine & Wyatt (1954)
A. indica infuscata Emden	Uganda and East Africa	Emden (1940), Evans (1951), LePelley (1959) and Nye (1960)
A. soccata Rondani	Morocco	Bleton & Fieuzet (1943).
A. varia soccata Rondani	Tropics and subtropics of old world	Hennig (1961) and many others.
A. excisa (Thomson)	Israel	Avidov (1961).
	Thailand	Meksongsee *et al.* (1968)
A. varia (Meigen)	Israel	Yathom (1965) and Avidov & Harpaz (1969)

Hennig (1961) considered the first four species of shoot fly, found in African, Indian and Mediterranean regions as synonyms of Atherigona varia soccata Rondani. Pont (1972) stated that the last two species were the misidentifications. He further advocated that sorghum shootfly was itself a single species and not a subspecies of A. varia (Meigen) and preferred A. soccata Rondani. According to him (1972) the latest taxonomic position of sorghum shoot fly was:-

Order - Diptera
Family - Muscidae (Deeming, 1971)
Subfamily - Phaeoniinae (Hennig, 1965 and Deeming, 1971)
Tribe - Atherigonini (Fan, 1965)
Genus - Atherigona (Rondani, 1856)
Species - soccata (Rondani, 1871)

Distribution

In India, sorghum shoot fly attacked cholam (sorghum) in the South (Fletcher, 1914 and Ballard & Ramachandra Rao, 1924). Malloch (1925) reported the fly to be present throughout South and Central India. Ponnaiya (1951a) observed it to be a serious pest of sorghum in Karnataka (Siruguppa). Since 1964, soon after the release of high yielding hybrids and varieties, it has assumed the status of a serious pest throughout the country (Vedamoorthy et al., 1965; Hiramath & Renukarya, 1966; Sandhu, 1969; Jotwani, 1969 & 1972a and Young, 1970).

Severe losses to sorghum have also been reported from Africa (Nye, 1960 and Barry, 1972c), Israel (Yathom, 1967a), Pakistan (Moiz & Naqvi, 1968) and Thailand (Meksongsee et al., 1968; Boonsom et al., 1970 and Sepsawadi et al., 1971).

Host Plants

The plants belonging to genus Sorghum were the principal hosts of sorghum shoot fly (Nye, 1960). Cholam or sorghum (Sorghum bicolor) and Johnson grass (S. helepense) were the first host plants recorded in India (Fletcher, 1920 and Ramachandra Rao, 1925). Jotwani et al. (1969) recorded the fly from Ragi or fingermillet (Eleusine coracana). Maize was also reported to be infested by this fly (Bleton & Fieuzet, 1943; Nye, 1960; Rivnay, 1962; Moiz and Naqvi, 1968 and Deeming, 1972). Both Ragi and maize were not the preferred hosts (Pont, 1972). Granados (1971) and Granados (1972) in Thailand reported the fly to breed on wild grasses (Digitaria ascendens, Brachiaria reptans and Eleusine indica). In all places, the shoot fly had strong preference for sorghum and it oviposited on the other hosts only when the primary host was not available.

Biology

Biology of sorghum shoot fly was studied by Ballard and Ramachandra Rao (1924), Ayyar (1933), Ponnaiya (1951a), Rao & Rao (1956), Awale (1970), Kundu & Kishore (1970), Young (1970), Pradhan (1971) and Singh (1971) in

India; Emden (1940), Bleton and Fieuzet (1943), Swaine & Wyatt (1954), Nye (1960), Deeming (1971), Barry (1972 a&b) and Breniere (1972) in different parts of Africa, Rivnay (1962), Blum (1963) and Avidov & Harpaz (1969) in Israel, Moiz and Nagvi (1968) in Pakistan and Meksongsee et al. (1968) and Granados (1972) in Thailand.

The distinguishing characters of adult fly were described by Ramachandra Rao (1924), Malloch (1925), Hennig (1961), Deeming (1971 & 1972) and Pont (1972).

Egg : The egg of shoot fly was reported to be opaque white, translucent, rod shaped, easily visible with naked eyes, size varying from 1.0 mm to 1.5 mm in length and 0.1 mm to 0.33 mm in breadth (Ballard & Ramachandra Rao, 1924; Ponnaiya, 1951a; Rao and Rao, 1956; Ritcher, 1959; Meksongsee et al., 1968; Kundu & Kishore, 1970; Young, 1970 and Singh, 1971). The distal face of egg was somewhat flattened and provided with two longitudinal vanes and surface sculptured that could differentiate eggs of other flies (Sandhu, 1972a). The longitudinal wrinkles appeared on empty egg shell (Ballard and Ramachandra Rao, 1924).

The incubation period was reported to be variable from place to place. In India, it was recorded to vary from 36-44 hours (Ballard & Ramachandra Rao, 1924) to 2-3 days (Ponnaiya, 1951a; Rao & Rao, 1956; Kundu & Kishore, 1970 and Singh, 1971). The eggs hatched in two

days in Israel (Blum, 1963), 2-5 days in Africa (Swaine & Wyatt, 1954; Nye, 1960 and Barry, 1972a) and 2-3 days in Thailand (Meksongsee et al., 1968 and Granados, 1972).

Blum (1963) observed that eggs hatched at night or in the early morning. Meksongsee et al. (1968) further noticed that eggs became creamy white after one day and hatched at night between 11 p.m. to 5 a.m. and the white empty shell remained on the leaf surface. Kundu & Kishore (1970) reported that before hatching, the egg became yellowish white and eclosion took place by rupturing the dorsal side below the tip of shell.

Larva : The newly hatched larva was reported to be almost colourless maggot, having fairly well developed sclerites of cephalopharyngeal skeleton and posterior pair of spiracles open (Ballard and Ramachandra Rao, 1924). Meksongsee et al. (1968) and Kundu & Kishore (1970) observed the maggot to be translucent and dirty white with body length slightly longer (1.4 x 0.16 mm) while Singh (1971) measured it to be slightly shorter (0.7x0.14 mm) than the egg shell. The duration of first instar was noticed to be 30-48 hours or 1-2 days (Ballard & Ramachandra Rao, 1924; Swaine and Wyatt, 1954; Kundu & Kishore, 1970 and Singh, 1971).

The second instar of the maggot changed to creamy white or dirty white and became bigger in size that varied from 1.72 mm to 2.86 mm (Kundu & Kishore, 1970 and

Singh, 1971). There developed an additional pair of spiracles (Ballard & Ramachandra Rao, 1924). The duration of second instar was recorded to be 2-4 days (Ballard & Ramachandra Rao, 1924; Swaine & Wyatt, 1954; Kundu & Kishore, 1970 and Singh, 1971).

The third instar larva was stout, quite conspicuous, cylinderical and yellow in body colour; with a black ring around the posterior pair of spiracles (Ballard and Ramachandra Rao, 1924; Ayyar, 1933 and Singh, 1971). Further morphological details were given by Avidov and Harpaz (1969) and Deeming (1971). According to Swaine and Wyatt (1954), Meksongsee et al. (1968), Kundu and Kishore (1970), Deeming (1971) and Singh (1971), the size was 5 to 9 mm in length and 0.7 to 0.8 mm in average breadth and this instar lasted for 3-4 days in summer and 5-9 days or more in winter. Kundu & Kishore (1970) reported four larval instars while earlier workers recorded only three instars. They (1970) termed the additional instar between the second and third instar and this observation was a matter of interest for other workers.

The total larval period from hatching to pupation was 6-15 days in India (Ballard & Ramachandra Rao, 1924; Kundu & Kishore, 1970 and Singh, 1971). The duration was reported to be 17 days in Israel (Blum, 1963), 9-13 days in Thailand (Meksongsee et al., 1968) and 13 days in Uganda (Barry, 1972 a&b).

Pupa : The mature larva generally pupated in plant tissues or it descended and pupated in soil (Ballard & Ramachandra Rao, 1924; Ayyar, 1933; Blum, 1963; Meksongsee et al., 1968; Kundu & Kishore, 1970; Young, 1970; Singh, 1971 and Barry, 1972a&b). The pupa was cylinderical, obtect, reddish brown to deep brown and became much darker before adult emergence. The size varied from 3.0 to 4.03 mm in India and Africa (Kundu & Kishore, 1970; Young, 1970; Singh, 1971 and Barry, 1972 a&b) and as big as 5 mm in Thailand and Israel (Meksongsee et al., 1968 and Avidov & Harpaz, 1969). The female pupa (3.7 mm) was found slightly bigger in size than male (3.2 mm) pupa (Singh, 1971).

Pupal period lasted for 6-7 days in South India (Ballard & Ramachandra Rao, 1924 and Ayyar, 1933) and 6-10 days in North India (Kundu & Kishore, 1970 and Singh, 1971), seven days in Israel (Blum, 1963), 7-9 days in Thailand (Meksongsee et al., 1968 and Granados, 1972), 6-8 days in East Africa (Swaine & Wyatt, 1954 and Nye, 1960) and 10.4 days in Uganda (Barry, 1972a).

Earlier in Morocco, Bleton and Fieuzet (1943) found that the pupal stage lasted for 7 days in summer and 40 days in winter. Deeming (1972) stated the pupal diapause during dry season in Nigeria. In India, Rao & Rao (1956), on the other hand, found no pupal diapause during offseason. Sandhu (1972b) added that low temperature in winter did not affect the pupal period in the Punjab.

Pradhan (1966) reported no adult emergence at 30-35°C and 15-20 per cent relative humidity. He (1971) prepared biometer for Atherigona soccata and presented a useful table giving the average total life for egg, larva, pupa and adult under different conditions of temperature and humidity.

Adult : The fly when emerged was pale white or pale yellow and turned to pale pink, with three pairs of black spots on the dorsal side (Meksongsee et al., 1968). The fly was reported to have dark brown antennae, eyes black, head silvery grey, thorax grey with its width 1 mm (Avidov & Harpaz, 1969 and Pont, 1972). The flies on an average, measured 4.42 to 5.2 mm in length (Kundu & Kishore, 1970); male was found to be smaller (3.5 to 4.5 mm) than the female (upto 5.2 mm) in length (Pont, 1972). The flies lived for more than a month (Ponnaiya, 1951a) in the South and for seven days in the North India (Kundu & Kishore, 1970; Anonymous, 1971; Pradhan, 1971 and Singh 1971). In Thailand fly survived for 13-28 days (Meksongsee et al., 1968 and Granados, 1972) and in Uganda, Barry (1972a) observed that adults lived for 12 days when caged over a sorghum seedling. The females lived longer than the males (Meksongsee et al., 1968 and Kundu & Kishore, 1970).

Under natural conditions, the total period from egg to adult was found to vary. It was worked out to be 16-29 days in India (Kundu & Kishore, 1970; Young,

1970 and Singh, 1971), 16-17 days in Tanganyika (Swaine & Wyatt, 1954), 24 days in Israel (Blum, 1963) and 18-20 days in Thailand (Meksongsee et al., 1968 and Granados, 1972).

Behaviour

Adult : Flies were reported to be very active, preferred sunshine and moisture and fed on honey dew and other sweet substances (Ballard & Ramachandra Rao, 1924) and have positive phototropic behaviour (Soto & Laxminarayana, 1971). The mating behaviour was noted by Ramachandra Rao (1924) and reported that premating period was 5-6 days and mating lasted for 7-8 minutes. The trifoliate process was considered to play an important role in courtship. The flies mated more than once (Deeming, 1971).

The oviposition behaviour was observed by Ballard & Ramachandra Rao (1924), Ponnaiya (1951a) and Swaine & Wyatt (1954). The fly preferred to lay eggs on the underside of the basal half of the topmost fully emerged leaf, parallel to the leaf veins. Egg laying started soon after germination of crop (Young, 1970) but more eggs were laid on second to fifth leaf than on other leaves (Ponnaiya, 1951a; Rao & Rao, 1956; Jain & Bhatnagar, 1962 and Krishnananda et al., 1970).

One egg, in general, was laid per plant, occasionally two or more eggs per leaf/seedling, which were perhaps laid by other females (Ballard & Ramachandra

Rao, 1924), were also recorded (Ponnaiya, 1951a; Rao & Rao, 1956 and Jain & Bhatnagar, 1962). Young (1970) and Jotwani (1972a) observed more than six eggs per seedling. Barry (1972a) and Soto (1972b) recorded still higher number of eggs per plant under artificial infestation conditions. More eggs were laid on the healthy plants, particularly in heavily manured and moist fields (Rao & Rao, 1956) or under irrigated conditions (Kundu & Kishore, 1970). Sandhu (1972c) observed that oviposition was affected by change in climatic conditions as egg laying was reduced or stopped during the period of very high temperature and/or continuous rainfall.

Swaine and Wyatt (1954) reported from Africa that eggs were laid usually at night but in India egg laying was observed to occur in the early hours of morning, soon after sunrise (Kundu & Kishore, 1970; Anonymous, 1971 and Pradhan, 1971). Ponnaiya (1951a) reported that one female could lay 39 eggs in its life time in two or three successive bursts. Kundu & Kishore (1970) observed that the female laid 20-25 eggs in its life span of 14 days. In Thailand, Meksongsee et al. (1968) reported that a female could lay 64 eggs.

Eggs were reported to be firmly glued to the leaf surface (Ballard & Ramachandra Rao, 1924) and were not normally washed with rain water (Sandhu, 1972c). However, in Uganda a good number of eggs were reported to be washed away with rain or even with morning dew (Barry, 1972a).

Larva : The behaviour of shoot fly larva was studied by Ballard & Ramachandra Rao (1924), Pannaiya (1951a), Rao & Rao (1956), Blum (1963), Meksongsee et al. (1968) and Kundu & Kishore (1970). The tiny maggot soon after hatching, migrated to dorsal surface of leaf after crossing the auricle and ligule, entered the space between the leaf sheat and the axis. It then travelled down to the base of the plant where it cut through the central shoot and severed it. Similar observations were reported by Ritcher and Rachie (1959), Young (1970) and Barry (1972 a&b). Blum (1963) also reported that dew in early morning helped the entry of the maggot into the tissues successfully.

As a result of larval attack, the central shoot withered and drooped down and formed a 'dead heart' (Ballard and Ramachandra Rao, 1924; Ramachandra Rao, 1924 Ayyar, 1933; Ponnaiya, 1951a; Blum, 1963; Young, 1970 and Barry, 1972a). They also stated that three instars of the maggot were completed in the decaying plant tissue. Ponnaiya (1951a) observed that larvae did not feed on the living tissue of the plant and in fact died if it could not sever the central shoot. Blum (1972a) emphasized that penetration and resumption of feeding were two different but consecutive actions. He also considered penetration as a mechanical process and no feeding was involved in it. Earlier, Bleton and Fieuzet (1943) reported that the maggot fed on the young tissues with their continuous

supply of sap. Doggett (1970) also stated that maggot fed inside on the lamina of infolded leaves. Kundu & Kishore (1970) observed maggot feeding on the growing point while Singh (1971) reported that larvae fed on healthy tissues.

It was commented that a sorghum seedling though infested with a large number of eggs, did not bear more than one maggot per shoot (Kundu & Kishore, 1970 and Barry, 1972a). Deeming (1972) noticed that in 10 out of 190 sorghum seedlings ~~that~~ contained more than one larva of Atherigona varia soccata Rondani in individual shoots of sorghum. Chander (1972) reported similar observation.

Nature of Damage

Attack of shoot fly was first noticed by Fletcher (1914); the boring maggot caused the characteristic 'dead heart'. Ramachandra Rao (1924) and Malloch (1925) considered it a pest of sorghum in South India. Ayyar (1933) described the 'dead heart' formation. It became the pest of minor importance of sorghum crop (Anonymous, 1951). According to Ponnaiya (1951a), October sowing often failed because of mass attack of shoot fly. Kadam and Patel (1955) reported it to be a serious pest in certain years and Rao & Rao (1956) observed 61 per cent infestation of the shoot fly from South India. The damage by Atherigona in experimental plots was 50-90 per cent to the kharif crop (Anonymous, 1962).

Seedlings were liable to be attacked upto four weeks after germination and seedlings older than this, usually escaped damage (Meksongsee et al., 1968 and Young, 1970).

Seasonal Incidence

The incidence of shoot fly varied considerably at different times and at different places. Ponnaiya (1951a) reported from South India that shoot fly injury was most common from late June to October and no activity was noticed from January to May. Similar observations were recorded by Rao and Rao (1956) and Ritcher (1959). Rao and Gowda (1967) noted that infestation was heavy in rabi sowings but mild in kharif sowings. Usman (1967 & 1968) showed that sorghum crop had high shoot fly infestation, up to 89.6 per cent 'dead hearts' formation, when sown during July-February; the period between March and July was safe for sorghum planting in Karnataka. Subhiah and Ibrahim (1968) reported high infestation (73 to 87 per cent) to rabi crop of sorghum sown during November-December while crops sown from March to October had very low infestation. Heavy fly incidence during kharif season was also reported from Karnataka (Raghunatha et al., 1972). Kundu et al. (1971) and Pradhan (1971) reported that the infestation was serious in August and September but incidence of shoot fly remained low from December to July in Udaipur (Rajasthan). Sharma (1968), at Delhi,

recorded that the fly was most active during March-April and again during mid-August to end of October. The peak periods of fly activity were further determined by Kulshreshtha et al. (1969), Sandhu (1969), Jotwani et al. (1970), Pradhan (1971) and Singh (1971). They concluded that the infestation was lowest in June and more serious in March, April and August to October with 50-70 per cent 'dead hearts' formation. Too hot weather during May-June and too cold weather during November-February and constant rains during July to mid-August restricted the activity of the fly (Jotwani et al., 1970; Singh, 1971 and Sandhu, 1972c). Krishnananda (1969) stated that in South, temperature had less effect but morning relative humidity showed pronounced effect on the incidence of shoot fly.

In East Africa, the shoot fly was reported troublesome in late planting from October onwards (Swaine and Wyatt, 1954) and in central and west Africa, damage was done to sorghum from June onwards (Deeming, 1971). Yathom (1967b) from Israel reported heavy attack of shoot fly on sorghum, sown in July-August. In Thailand, the pest reached its peak in July and declined in August-September and again reached a second peak in December (Granados, 1971 and Granados, 1972).

Such studies were helpful to pin point the actual safe period for sorghum crop from shoot fly infestation, which could be manipulated for insect control.

Host Plant Resistance

Ponnaiya (1951b) screened 202 varieties of sorghum and found that 15 of these were less attracted for oviposition. Rao and Rao (1956) screened 42 varieties and found 14 of them to exhibit a fair amount of resistance to fly attack. Jain and Bhatnagar (1962) at Ajmer, exposed 198 varieties of sorghum to shoot fly for oviposition and found that four were least preferred for oviposition and considered as highly resistant.

Under the All India Sorghum Improvement Project of ICAR and Cooperative Agencies, a large number of world's germplasm of sorghum was screened for shoot fly resistance. More than twelve thousand varieties of sorghum were tested in non-replicated trials (Anonymous, 1965, 1967, 1968, 1969, 1970 & 1971; Singh et al., 1968; Chachoria and Taylor, 1970 and Pradhan, 1971) and a little more than one thousand promising varieties of sorghum were further tested in replicated trials (Anonymous, 1970, 1971 & 1972; Jotwani et al., 1971; Shri Ram, 1971 and Pradhan, 1971). Besides these, fortyfive varieties were tested in International Replicated Trials conducted in Thailand, Israel, Uganda and Nigeria (Young, 1972).

Selected lines that exhibited field resistance were further tested under artificial infestation in the green house for shoot fly resistance (Soto, 1971b). He (1972b & 1974) stated that the laboratory results were not

in accordance with those reported in the field and as high as 85-98 per cent 'dead hearts' were obtained corresponding to 41-58 per cent 'dead hearts' reported under field conditions. The phenomenon of non-preference for oviposition, of course, was operative and observed that more eggs were laid on susceptible varieties when given a choice; though leaf colour and texture were the same (Sotoslaj & Rao (1972a) listed thirty-seven Indian sorghum varieties (including IS 1054, 2123, 5470, 5566, 5604 and 5622) as most resistant to shoot fly attack due to non-preference for oviposition.

Blum (1965) in Israel screened sorghum germplasm consisting of 250 varieties for resistance to stem fly and reported several varieties from India as highly resistant. He (1967b) evaluated five lines from India with two local (Israel) sorghums, under natural and artificial infestation and reported that three varieties were non-preferred for oviposition. Rangdang et al. (1970 1&2) in Thailand screened sorghum varieties and have shown non-preference for oviposition to shoot fly in green house and field experiments.

The varieties possessing foliage with dark green colour and with waxy bloom appeared to be comparatively more attractive for oviposition than varieties having foliage with bright green colour (Vedamoorthy, 1965). Flies preferred only the susceptible varieties for oviposition both under field and insectory conditions

(Krishnananda, 1969). More eggs were laid on susceptible CSH-1, CSH-2 and Swarna and least number of eggs on the resistant varieties IS 1054, IS 5470 and IS 5604 (Anonymous, 1971; Jotwani et al., 1971; and Jotwani et al., 1971). Sepsawadi et al. (1971) also reported similar behaviour of fly in Thailand.

The phenomenon of antibiosis in sorghum varieties to shoot fly was studied inadequately. Toughness or strength of plant tissues has been associated with resistance of plants to insects (Painter, 1951; Chesnokov, 1962 and Beck, 1965), strength of the plant tissue was ascribed to the number of vascular bundles per unit area and the degree of lignification of various vascular bundles (Chesnokov, 1962). Ponnaiya (1951b) investigated physical barriers within the young plants which might cause resistance to shoot fly damage and reported that seedlings of resistant varieties have more lignified tissues as compared to susceptible ones at the zone of attack of Atherigona soccata. Blum (1968 & 1969a) found that resistant varieties were characterized by a distinct lignification and thickening of the cell walls enclosing vascular bundles within the central whorl of young leaves.

Silica deposition in the leaf sheath of early stages of sorghum plant was considered to restrict shoot fly maggot (Ponnaiya, 1951b). Blum (1968) further stated that all resistant varieties as compared to susceptible

one, possessed a much greater density of silica bodies (dumb-bell shaped, intercostal and silicified prickle hairs) in the abaxial epidermis at the base of first, second and third leaf sheaths. The density increased from first to third leaf sheaths. Langham (1968) thought that prickle hairs on the leaf sheaths were involved in the antibiosis to shoot fly larva.

Antibiosis has been shown by Blum (1967b), who found that many larvae died between the leaf sheaths before reaching the growing point in case of resistant varieties and which those survived were generally smaller and less vigorous than the larvae in the susceptible varieties. The mechanism of antibiosis was studied by Krishnananda (1969) in nineteen varieties and found that IS 5566, IS 5285 and IS 5613 were uniformly resistant. In case of IS 5566, the larval period prolonged by 6.3 days and shortened the adult longevity remarkably. The fecundity of the fly was greatly decreased when reared on a resistant variety, though the viability of eggs was not affected. The size and weight of the insects remained unaltered on all varieties. The larvae could not establish well on the resistant variety in view of its high antibiosis. Blum (1972b) reported that ten days after oviposition, significantly fewer larvae were found in resistant variety (221) as compared to the susceptible one. He also observed that complete 'dead heart' was not formed instead there was a malformed shoot. Young (1972) reported characteristic

antibiosis in varieties IS 5801 and IS 5604 which gave good results in All India Sorghum Development Projects. Rajurkar and Thakare (1973) also observed that all plants those bear eggs did not necessarily turned into 'dead hearts'. Soto (1974) observed some degree of antibiosis with regard to the larval survival and adult emergence in IS 2123 and IS 1054 and variety Swarna which seemed to operate at low level.

This literature reveals that our knowledge on the biology of sorghum shoot fly is inadequate for developing suitable and effective control of this pest. The mechanism of resistance has been demonstrated to be non-preference for oviposition in a few lines of sorghum germplasm which when exposed to high pest population pressure, fail to give satisfactory performance, not much evidence of antibiosis is available. Plant breeders in collaboration with entomologists are engaged to evolve suitable resistant varieties which could be integrated with other techniques of control measures but for lack of proper selection of resistant line of sorghum, no achievement could be made in the field of breeding for resistance to Atherigona soccata Rondani.

Chapter III

MATERIALS AND METHODS

The present investigations on the "biology of sorghum shoot fly, Atherigona soccata Rondani with reference to the phenomenon of antibiosis" were carried out at the Department of Entomology, Punjab Agricultural University, Ludhiana from 1971 to 1974. However, during 1971, some observations on biology and behaviour of the fly were also recorded at the Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.

BIOLOGY

The life history and behaviour of sorghum shoot fly were studied in the field under natural infestation on susceptible sorghum hybrid CSH-1 (ms CK 60A x IS 84). Since the activity of fly was higher during April and September, investigations were usually carried out during these months. Preliminary observations on life history were made during 1971 but detailed studies were carried out during 1972 and 1973. Studies on the seasonal incidence of shoot fly were conducted for three years from 1971 to 1973. However, the seasonal life history was studied only during 1972-73.

Seedlings of sorghum used in different experiments were raised in earthen pots (20 x 15 cm), wooden flats (45 x 30 x 10 cm) and in the field plots (5 x 4 m). In each pot, plant population varied from one to five and in flat 30 to 50. In each of the field plot, eight rows were sown at 45 cm apart and on emergence, seedlings in a row were spaced to 4-5 cm apart so as to accomodate about 40 to 50 seedlings per row. However, during summer (May-June) and winter (November-February), the plants per row were less because of poor germination due to high as well as low temperatures respectively.

Normal cultural practices, as recommended for sorghum crop, were followed. In addition, water was applied to pots and flats every evening and the field plots were flood irrigated at weekly intervals depending upon weather conditions.

The biology of sorghum shoot fly was studied during September, 1972, under field conditions. Sorghum CSH-1 was sown on 23rd August and it germinated on 27th August, 1972. At one leaf stage, 200 seedlings of uniform growth, from third to seventh row of the plot, were tagged and marked with serial numbers. Another lot of fifty seedlings in rows other than third to seventh, were marked by inserting aluminium markers close to seedlings. Detailed observations on egg, larva, pupa and adult and on behaviour of adult and larva were recorded on the marked seedlings from one leaf stage to eight leaf stage.

Information pertaining to different stages of life history, behaviour and resistance to shoot fly was collected in the following manner:-

1. Life history

(a) Egg : Freshly laid eggs were collected by clipping off a small portion of leaf carrying egg, in a Petri dish containing wet sponge. Colour, shape and microscopic details were recorded. The size of freshly laid eggs and 6 and 24 hours after egg laying was measured with the help of ocular micrometer. The egg shell after hatching was also measured.

Changes in colour of egg that occurred from oviposition to hatching were observed. The incubation period was observed during April and September, 1972 and 1973. Time of hatching of egg was noticed during April and September, 1972, at two-hour intervals starting from 0600 to 1800 or 1900 hours. Observations on hatching were also recorded during night as well, at two-hour intervals. The process of egg hatching was watched; eclosion was also observed in the field with the help of magnifying lens.

(b) Larva : The colour, shape and other prominent characters of different instars of the larva were examined. The tiny maggots soon after emergence were collected with the help of a wet camel hair brush, from the leaf surface itself and after eight and thirty hours of feeding from the plant tissues. Second instar and

third instar (newly formed and full grown) larvae were collected at appropriate intervals from the experimental plot, for measurements. To know the number of larval instars and duration of each instar, five seedlings were dissected (sheaths unrolled) after egg hatching, till the full grown maggot showed the signs of pupation. The material was examined under the binocular. The presence of exuviae was considered as date of moulting and when maggot became prepupa, it was taken as duration of third instar.

(c) Pupa : The full grown maggots when showed slight inactivity and tendency to contract in size, were collected in Petri dishes, containing wet filter paper. The period of complete inactivity till formation of pupa, was taken as prepupal period. The size, colour, duration and general external characters of both prepupa and pupa were recorded. Male and female pupae were differentiated. The period from complete immobility of prepupa to the emergence of adult was taken as pupal period.

(d) Adult : The emergence of adult in the laboratory as well as in the field and different changes right from emergence to flying stage were recorded. Longevity of adults was noted in captivity. Male and female flies were segregated on emergence from 100 pupae collected from the field and sex ratio was worked out.

2. Behaviour

(a) Adult : Behaviour of adult for feeding, mating and oviposition was studied in detail. Some of the observations were also made at Hyderabad in the cages (Fig. 1). Glucose (dry) and brewer's yeast (powder) were served in watch glasses to flies inside the rearing cages. Observations on mating were recorded usually in the morning hours and the role played by male and female flies was studied in about twenty cases. The process of egg laying was seen.

The period of egg laying was recorded on seedlings in pots and in the field. Ten pots each containing five seedlings of three to four leaf stage, were kept in the field for 36 hours. Egg count was taken from 0600 to 1800 hours at two-hour intervals during April, 1972. Similar observations on seedlings in the field were made during September, 1972. Egg count was recorded on fifty labelled seedlings daily from 0600 to 1900 hours at two-hour intervals and continued for a week, during which period plants grew from two leaf to four leaf stage seedlings. To observe oviposition during night hours, ten pots each with five seedlings were scattered in the field at 2000 hours. These pots were then brought back to screen house in lots of two at two-hour intervals. Egg count on seedlings was taken in the morning. Observations were repeated twice.

Fig. 1. Shoot fly rearing cage (300 x 80 x 90 cm)

Experiments were conducted to know the preference of shootfly for oviposition for a particular leaf or stage of seedling. Ten pots each having three emerging seedlings, were exposed to natural fly population during September, 1971 and eggs were counted and brushed off on alternate days. It was continued till the plants reached seven leaf stage. Further in April, 1972, seedlings were raised in ninety pots each having three seedlings, in such a way that each lot of ten pots contained coteledonary leaf stage to eight leaf stage seedlings. All these pots were then randomly scattered in 25 days old sorghum field for 36 hours (from 0600 hours to 1800 hours of next day). Eggs on different leaves were counted to observe the preference of leaf and stage of the seedling for oviposition.

Again in April, 1972, the oviposition behaviour was recorded on fifty marked seedlings as they grew from one leaf stage to eight leaf stage in a period of about one month. Egg count was taken at three or four-day intervals, when a new (one more) leaf appeared. Egg count was continued even on those seedlings where 'dead hearts' were formed. Oviposition preference for the stage and age of seedling was thus obtained.

(b) Larva : Observations on the movements of tiny maggot on the leaf surface and on its downward journey to reach the plant base were recorded in the field and also on potted seedlings. The infested seedlings at

different intervals after larval penetration, were cut open (the sheaths unfolded) and the nature of cut at the base by the maggot was observed in a large number of plants. The presence of different larval instars in different tissues of the affected plants was observed and the site of moulting (with the presence of exuviae) was also examined.

The feeding behaviour of the three instars was observed. The freshly emerged tiny maggots picked up from leaf surface, were released in the funnel of the same leaf or maggots obtained from the infested plants were further released in the funnel of healthy seedlings. In the laboratory the maggots were also released on decaying tissues obtained from shoot fly infested 'dead hearts' of sorghum. Observations were also made on the migration of larva from mother shoot to tiller or to other shoots. Plants bearing more than one egg were also observed for the number of maggots. Symptoms that appeared after the larval penetration and the time taken for the formation of complete 'dead heart' were also recorded.

3. Seasonal Incidence

(a) Incidence : To determine the periods of high and low incidence of sorghum shoot fly under natural field conditions, studies were conducted during 1971 to 1973. A field of 60 x 10 m was laid out into thirty plots of 5 x 4 m. Sorghum hybrid CSH-1 was sown in each plot

at ten-day intervals from March to June, 1971 and then at weekly intervals from July to November, 1971 and from February, 1972 to November, 1973.

Observations were restricted on inner five rows (third to seventh), each row represented a replication. Non-experimental rows were provided outside the experimental area.

Data were recorded on the date of sowing, date of germination and total seedlings per replication.

After germination, egg count at weekly intervals for a month was recorded on five randomly selected plants in a row i.e. 25 plants per plot. The number of 'dead hearts' formed due to shoot fly attack per week for four weeks was also counted. After each count, plants with 'dead hearts' injury, were uprooted which were either used for biological observations of fly or were destroyed.

Each planting except the November sowing was completely uprooted after fourth count in a month to prevent infestation to later sowings. The November sowing was rather harvested from soil level at weekly intervals so as to give rise to tillers during December and January.

Since there was no germination of sorghum during winter months, observations were recorded either on tillers or on seedlings raised in the flats. The flats with seedlings at 2-3 leaf stage were kept near water channals

where the fly was observed to breed continuously on baru (Fig. 2).

The weekly data on average number of eggs per plant and percentage of 'dead hearts' were worked out for each month. The data were analysed for phenotypic correlation coefficients by using standard procedure.

(b) Seasonal life history : Studies were carried out continuously from September, 1972 to December, 1973. Observations were taken on ten randomly selected uniform seedlings from the non-experimental rows of the plots. Date of oviposition, hatching of egg and the emergence of adults and their longevity were recorded.

Seedlings of desired leaf stage from an appropriate plot were selected from the non-experimental area. In the evening all the seedlings bearing un-hatched eggs were either uprooted or the eggs were brushed off. Next day at 1100 hours, ten seedlings with fresh eggs, were tagged (bearing serial number and date of oviposition). Where the sufficient number (ten plants) was not available on a single day, required number of plants with fresh eggs were tagged on the following day. During June and November to February some seedlings were artificially infested by using the technique of Jotwani and Srivastava (1970) to obtain ten infested seedlings.

The generations were studied one after the other and continued for more than a year. The number of

Fig. 2. Sorghum seedlings in flats placed along the water channel during winter

life cycles of shoot fly from September, 1972 to September, 1973, gave the number of generations per year.

The egg period was observed during different months. The larvopupal period was taken into account from the date of egg hatching to the date of adult emergence. The tagged infested plants were uprooted after 12-15 days during March to September and 15-20 days during October to February of oviposition. These were placed in glass jars (20 x 15 cm) containing wet sponge at bottom. Then the jars were covered with muslin cloth for adult emergence. Date of adult emergence was recorded. The adults were later fed on glucose and yeast and their longevity in glass jars was also taken into account.

Pupal period was worked out separately by dissecting the affected plants, uprooted from other rows of the plot. This period was then subtracted from the total larvopupal period to get the larval duration for each generation.

Since the full grown larva tended to select a site having more humidity for pupation; observations were recorded during different seasons.

RESISTANCE TO SHOOT FLY

The promising lines of sorghum exhibiting field resistance were obtained from the World Sorghum Collection maintained at Hyderabad and Delhi. Various sorghum lines and cultivars involved in this study are enlisted here.

S.No.	Lines/ Cultivars	Group	Pedigree	Origin
1.	IS 1054	49-Cernuum	Maldandi 35-1, Poona, Maharashtra	India
2.	IS 2123	41-Durra	PI 195683	U.S.A.
3.	IS 4476	41-Durra	Dodar, Kadri, M.P.	India
4.	IS 4567	49-Cernuum	Khod Tarparkari, Maharashtra	India
5.	IS 5072	41-Durra	Tella Jonna,Bramhan Kurnool, A.P.	India
6.	IS 5383	49-Cernuum	Karuvalur, Coimbatore, T.N.	India
7.	IS 5469	41-Durra	Hingar Jola Myamathi, Shimoga, Karnataka	India
8.	IS 5470	41-Durra-Medium	Yanagar Jola Sorathur, Shimoga, Karnataka	India
9.	IS 5566	43-Durra/ membranaceum	Jola bapur,Raichur, Karnataka	India
10.	IS 5604	43-Durra/ membranaceum	Allu Jola Jowargi, Gulborga, Karnataka	India
11.	IS 5622	41-Durra	Kada Jola Tadawalya,Karnataka	India
12.	IS 8315	41-Durra	Jowar, Kutch, Gujarat	India
13.	Swarna	Caffrorum	S-413 (IS 3924), SA 9804	U.S.A.
14.	CSH-1	Hybrid	ms CK 60A x IS 84	India
15.	CSH-3	Hybrid	ms 2219A x IS 3691	India

Information regarding lines at serial No. 2, 3, 4, 6, 11, 12, 13, 14 and 15 was communicated by Andrews (1974).

(a) Non-preference : Twelve promising lines of sorghum (mentioned above) which were reported to be relatively resistant to the attack of shoot fly, were sown in pots to have one seedling per pot. Two susceptible checks namely Swarna and CSH-1 were also included in this experiment. It was replicated five times. Seedlings raised to one leaf stage in screen house were exposed to natural fly infestation during September, 1972, when the fly had higher rate of activity under field conditions.

Observations were recorded twice daily at 0900 and 1800 hours on the number of eggs laid on each leaf per plant, number of plants having eggs and the number of seedlings developing 'dead heart' injuries, in each line. Observations were continued upto six leaf stage of seedlings. The sorghum lines found to be non-preferred for oviposition or showing less 'dead hearts' as compared to susceptible checks, were taken for further studies.

During September, 1973, seven promising lines of sorghum namely, IS 1054, IS 2123, IS 5383, IS 5470, IS 5566, IS 5604 and IS 5622 and three cultivars viz. Swarna, CSH-1 and CSH-3 were randomly sown in three metre long furrows in the field, replicated thrice.

Observations on number of eggs laid per leaf/ plant on 20 seedlings per replication (60 plants per variety) were recorded. Further, the number of plants bearing eggs and number of 'dead hearts' formed in each variety, were recorded. The data presented as a mean of

three replications, were then statistically analysed for analysis of variance.

(b) Antibiosis : For antibiosis studies, six lines namely IS 1054, IS 2123, IS 5470, IS 5566, IS 5604 and IS 5622 which were considered to be more resistant to shoot fly than others including two susceptible checks, Swarna and CSH-1, were sown in three metre long rows in two replications. Observations on 20 selected (three or four leaf stage) seedlings were taken for number of plants with eggs, number of 'dead hearts' formed and number of survivals or recoveries from 'dead heart' injuries. The data were then statistically analysed.

Observations on incubation period of egg, larvo-pupal period, pupal period and the adult longevity (in captivity) were made in each case. The 'dead hearts', 12-15 days after infestation were placed in jars to collect the adults. From some of the plants, full grown larvae were taken out in Petri dishes for pupation.

Symptoms of withering after larval penetration and time taken for 'dead hearts' formation were recorded in each line.

To find out the basis of resistance, three lines, IS 5566, IS 5604 and IS 5470 considered to be comparatively resistant and having antibiosis effect on shoot fly, were sown in the field during April, 1974, along with two susceptible checks, Swarna and CSH-1. Samples of leaf

sheaths from the larval penetration zone of third, fourth and fifth leaf sheaths at three, four and five leaf stages respectively, were taken. Five spodograms of each leaf sheath in each variety were prepared as per the technique of Ponnaiya (1969) as it was considered more convenient without using 'muffle' furnace and with least distortion of ashes on the slides.

After adding a drop of xylol, the slides were examined under the microscope. Size of silica particles were measured with the help of ocular micrometer. The pattern of silica bodies was noted. Density of silica bodies both dumb-bell and irregular shaped were counted per mm^2 in each case. The mean values of five readings were taken for interpretation of the data.

METEOROLOGICAL DATA

The meteorological data pertaining to temperature, relative humidity and rainfall for the years 1971 to 1973 are given in Appendix I. Temperature records for the laboratory are also given in Appendix II.

Chapter IV

EXPERIMENTAL RESULTS

The findings of the present investigations conducted during 1971 through 1974 are described under the following heads:-

A. Biology of Atherigona soccata Rondani
   1. Life history
   2. Behaviour
      (a) Adult
      (b) Larva
   3. Seasonal incidence
   4. Seasonal life history

B. Host non-preference studies for oviposition on promising varieties of sorghum.

C. Antibiosis studies in different promising varieties of sorghum.

A. Biology of sorghum shoot fly, A. soccata

Studies on the biology of sorghum shoot fly were initiated during the year 1971 on sorghum hybrid CSH-1 and preliminary information was obtained. The detailed studies, however, were carried out during the year 1972-73.

1. Life History

The life history of shoot fly was studied in the field during September, 1972, the peak period of its

activity. The observations on different stages of the life cycle of shoot fly, viz. egg, larva, pupa and adult, are enumerated here.

Egg : The freshly laid eggs were shining opaque white in colour and elongate in shape (Fig. 3). Microscopic examination revealed the sculptured reticulate surface of egg with two distinct longitudinal vanes. The distal end was somewhat flattened, while the micropyler end was pointed. Slight variations in size of egg with age were noticed. The freshly laid egg measured on an average 1.397 x 0.291 mm, while the eight hour old and 24 hour old eggs measured 1.394 x 0.316 mm and 1.377 x 0.325 mm respectively (Fig. 4). However, the shell of the hatched egg measured 1.235 x 0.183 mm (Table 1).

Colour of the egg changed to whitish grey before hatching. The incubation period varied from 24 hours to 72 hours. During April and September the majority of eggs (52.6 to 70.0%) took 36-48 hours for hatching, while 13.0 to 28.0 per cent of the eggs took 24-36 hours to complete the incubation period (Table 2).

During April, as many as 6.3 to 7.5 per cent eggs took up to three days to hatch and only 2.0 to 3.0 per cent hatched within 24 hours. In September, 10 to 12 per cent eggs completed the incubation period within one day and a very few (4.0 to 5.4 per cent) took more than two days to hatch. More eggs remained unhatched in April than in September.

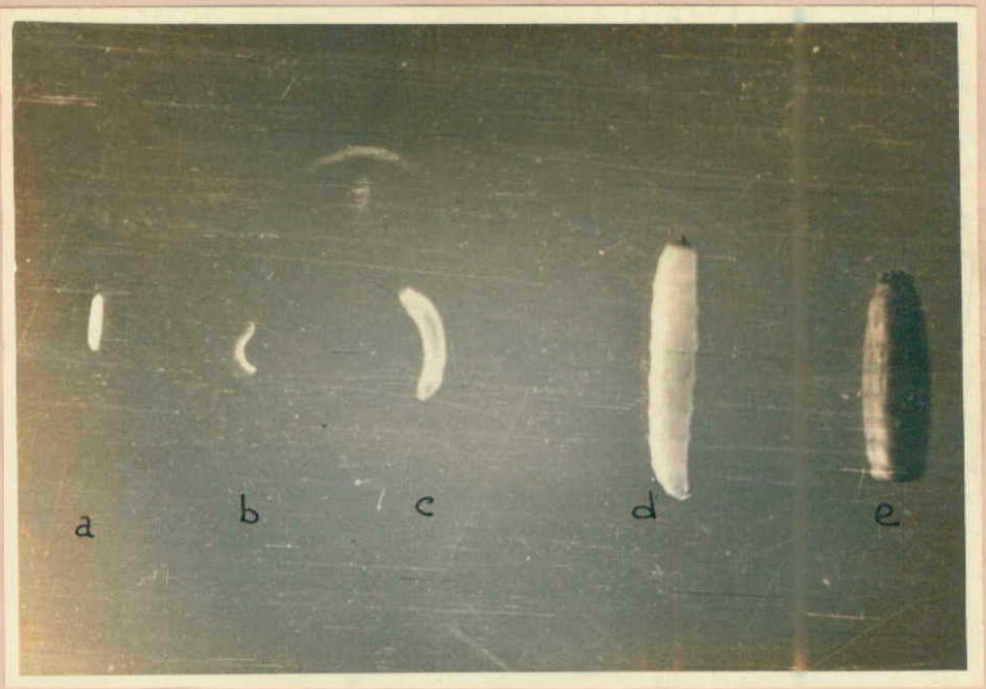

Fig. 3. Stages of sorghum shoot fly

a. Egg
b. First instar
c. Second instar } Larva
d. Third instar
e. Pupa

Table 1

Measurement of egg of sorghum shoot fly, Atherigona soccata Rondani at different intervals (mm)

Observations	Freshly laid		Eight hours old		24 hours old		Hatched egg shell	
	Length	Breadth	Length	Breadth	Length	Breadth	Length	Breadth
1	1.398	0.295	1.394	0.299	1.368	0.310	1.192	0.193
2	1.402	0.295	1.394	0.309	1.389	0.326	1.262	0.197
3	1.402	0.314	1.398	0.322	1.378	0.326	1.307	0.201
4	1.402	0.295	1.398	0.333	1.387	0.333	1.246	0.193
5	1.398	0.288	1.383	0.326	1.387	0.318	1.250	0.185
6	1.402	0.291	1.390	0.303	1.326	0.318	1.269	0.173
7	1.398	0.291	1.390	0.310	1.387	0.314	1.192	0.173
8	1.394	0.291	1.387	0.295	1.378	0.326	1.267	0.197
9	1.398	0.291	1.402	0.333	1.374	0.314	1.188	0.173
10	1.398	0.288	1.398	0.299	1.387	0.318	1.220	0.173
11	1.398	0.284	1.390	0.303	1.368	0.326	1.195	0.170
12	1.383	0.280	1.395	0.328	1.378	0.333	1.255	0.185
13	1.402	0.291	1.397	0.333	1.387	0.337	1.198	0.173
14	1.398	0.284	1.395	0.326	1.387	0.341	1.245	0.185
15	1.394	0.288	1.400	0.326	1.378	0.333	1.250	0.173
Average	1.397	0.291	1.394	0.316	1.377	0.325	1.235	0.183

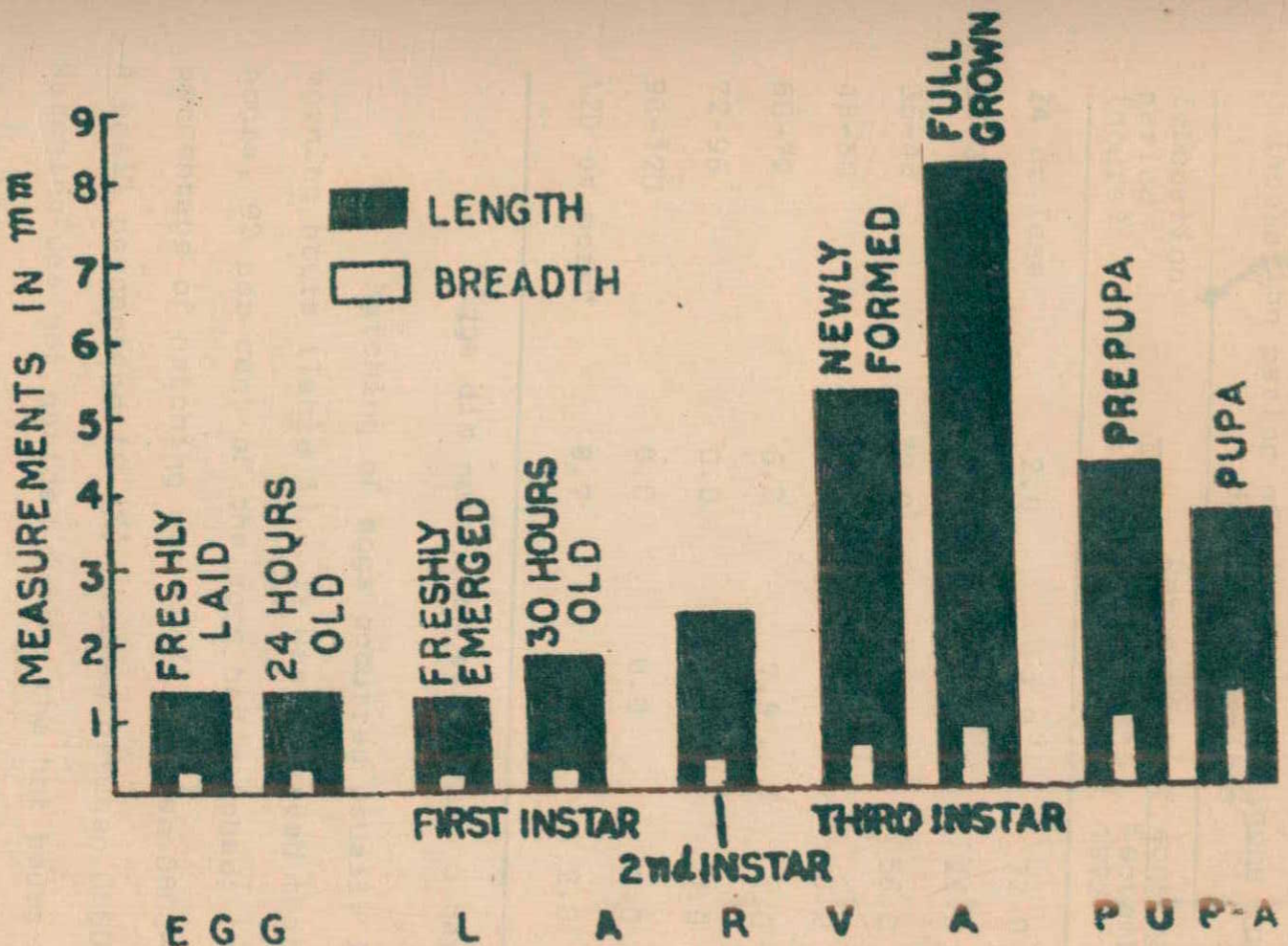

FIG.4 SIZE OF DIFFERENT STAGES OF SORGHUM SHOOT FLY, ATHERIGONA SOCCATA RONDANI

Table 2

Incubation period of eggs of Atherigona soccata during different periods

Incubation period (hours)	Percentage of eggs hatched during			
	April 1972	April 1973	September 1972	September 1973
24 or less	2.0	3.0	12.0	10.7
24-36	13.0	13.3	26.0	28.0
36-48	70.0	64.2	56.0	52.6
48-60	0.0	3.0	0.0	0.0
60-72	6.3	7.5	4.0	5.4
72-96	0.0	0.0	0.0	0.0
96-120	0.0	0.0	0.0	0.0
120 or more*	8.7	9.0	2.0	3.3

*Eggs did not hatch even after 5 days

Hatching of eggs occurred usually in the early morning hours (Table 3). It was observed that by 0800 hours, 92 per cent of the eggs had hatched; the maximum percentage of hatching was (54%) between 0600-0700 hours. A small percentage (2-4%) hatched between 0800-1000 hours. Hatching was not noticed during the hot hours of t he day or in the evening hours. Observations on eggs, kept in Petri dishes, showed no egg hatching during night as well.

In the process of hatching, the dorsal side of microplyer end of the egg got ruptured and the larva

appeared with its head out. Further, the larva took two minutes to come out of the egg shell.

Table 3

Hatching of Atherigona soccata eggs at different hours of the day during September, 1972 (Total eggs observed = 50)

Time of hatching (hours)	Number of eggs hatched	Percentage of hatched eggs	Cumulative %age of hatched eggs
Before 0600	12	24	24
0600-0700	27	54	78
0700-0800	7	14	92
0800-0900	1	2	94
0900-1000	1	2	96
1000-1100	0	0	-
1100-1200	0	0	-
1200-1600	0	0	-
1600-1800	0	0	-
After 1800	0*	0	-

*Two eggs did not hatch

Larva : The first-instar larva was observed to be tiny but active and semi-transparent to dirty white in colour (Fig. 3). On microscopic examination, it was noticed that cephalic segment bore black incurved hooks which were extended up to fourth segment. The anterior end of maggot was tapering and the posterior one possessed a pair of spiracles.

The newly emerged larvae were found slightly smaller than the egg and varied in size from 1.258 to 1.350 mm (average 1.284 mm) in length and 0.170 to 0.185 mm (average 0.176 mm) in breadth (Table 4). However, a significant increase in size was noticed after 10 and 30 hours of feeding when the average size measured 1.62 x 0.18 mm and 1.80 x 0.19 mm respectively (Fig. 4).

The colour of the larva later changed to lustrous creamy white and the cephalic hooks became stout. The maggots possessed eleven segments. Moulting took place 36-48 hours after hatching, inside the plant tissues. Exuviaewere usually present 5-10 mm above the growing point.

Second instar larvae were dirty white to creamy white in colour and comparatively larger in size with an average length of 2.35 mm and breadth 0.37 mm (Table 4; Fig. 3 & 4). Cephelic hooks became thicker and maggots possessed eleven segments. This instar lasted for 2-3 days. Exuviae were located in semi-rotten tissues about 2 cm above the growing point.

Third instar larvae were observed to be yellow to deep yellow in colour, quite stout, conspicuous, cylinderical in shape with tapering anterior end (Fig. 3). The black prominent ring round the posterior pair of spiracles and cephelopharyngial skeleton in maggots were heavily sclerotised. At the anterior end maggots possessed additional pair of spiracles, rosette type and yellow in

Table 4

Measurement of larva of shoot fly, Atherigona soccata Rondani at its different stages of development (m

Observation	First instar						Second instar		Third instar			
	Newly hatched		10 hours old		30 hours old				Newly formed		Full grown	
	Length	Breadth	Length	Breadth	Length	Breadth	Length	Breadth	Length	Breadth	Length	Breadth
1	1.251	0.170	1.59	0.181	1.80	0.185	2.25	0.341	5.40	0.585	8.05	0.758
2	1.258	0.174	1.62	0.189	1.82	0.193	2.40	0.382	5.25	0.573	8.25	0.763
3	1.258	0.174	1.62	0.185	1.78	0.189	2.35	0.371	5.10	0.565	7.80	0.818
4	1.273	0.178	1.62	1.181	1.80	0.189	2.50	0.382	4.80	0.523	8.40	0.795
5	1.265	0.170	1.64	0.193	1.78	0.189	2.50	0.379	5.50	0.573	8.50	0.788
6	1.343	0.178	1.62	0.185	1.82	0.193	2.45	0.375	5.40	0.581	8.55	0.826
7	1.350	0.181	1.59	0.193	1.80	0.197	2.20	0.363	5.35	0.593	8.60	0.826
8	1.288	0.178	1.66	0.181	1.80	0.185	2.25	0.367	5.50	0.597	8.80	0.803
9	1.265	0.178	1.62	0.185	1.82	0.204	2.30	0.371	5.35	0.573	8.35	0.841
10	1.273	0.185	1.59	0.181	1.78	0.197	2.35	0.379	5.50	0.585	8.00	0.788
11	1.273	0.178	1.59	0.181	1.86	0.185	2.40	0.367	4.80	0.577	8.65	0.770
12	1.281	0.170	1.66	0.185	1.78	0.189	2.45	0.371	5.20	0.593	7.65	0.788
13	1.343	0.181	1.62	0.185	1.80	0.197	2.30	0.382	5.10	0.581	8.00	0.803
14	1.261	0.170	1.62	0.181	1.78	0.204	2.30	0.363	5.50	0.593	8.65	0.818
15	1.273	0.178	1.59	1.189	1.78	0.185	2.25	0.371	5.35	0.573	6.80	0.841
Average	1.284	0.176	1.62	0.184	1.80	0.193	2.35	0.371	5.27	0.577	8.20	0.802

colour and the posterior pair of spiracles were black with spiracular lobes quite distinct. The newly transformed instar measured 5.31 mm in length (Table 4) which increased to 8.2 mm when full grown during the period of 5-6 days (Fig. 4).

The male and female maggots were found to show no particular difference except in breadth, the thinner (< 0.8 mm) maggots usually turned out to be male flies.

Pupa : The full grown larva stopped feeding and rested at a suitable place normally in the lower part of the plant in well rotten tissues. It then contracted in size (4.25 mm in length) and colour changed to deep yellow, or light brown, with posterior spiracle ring prominently black. This stage has been termed as prepupal stage and it lasted for 6-8 hours. The last larval skin formed the puparium and no spinning to form a cocoon was noticed.

The pupa of the shoot fly was reddish brown to dark brown, barrel shaped (obtect type) with black and flattened posterior end and round anterior end, fitted with a circular disc. Nine segments remained visible (Fig. 3).

The data on the size and duration of prepupal and pupal stages in Table 5 show that the size of pupa varied from 3.20 to 4.00 mm in length and from 1.15 to 1.35 mm in breadth with an average of 3.60 x 1.23 mm (Fig. 4). The pupal stage lasted for 6-8 days.

Table 5

Size and duration of prepupa and pupa of Atherigona soccata during September 1972

Observations	Measurements in mm				Duration of	
	Prepupa		Pupa		Prepupa (hours	Pupa (days)
	Length	Breadth	Length*	Breadth		
1	4.20	0.92	3.85	1.25	7	7
2	4.40	0.90	3.70	1.20	6	6
3	4.50	0.86	3.35	1.15	8	8
4	4.40	0.86	3.30	1.15	8	6
5	4.20	0.90	3.20	1.20	8	8
6	4.10	0.88	3.90	1.35	7	8
7	4.40	1.00	3.80	1.35	5	7
8	4.50	0.88	3.40	1.20	8	7
9	3.90	0.96	3.30	1.25	7	7
10	4.00	0.90	3.90	1.30	7	7
11	4.35	0.98	3.30	1.15	8	8
12	4.15	0.90	3.25	1.15	7	6
13	4.40	1.10	3.80	1.25	7	7
14	4.35	0.98	4.00	1.30	6	7
15	3.90	0.80	3.85	1.20	7	8
Average	4.25	0.91	3.60	1.23	7	7.1

*Pupae of 3.40 mm or less in length turned to male flies

Adult : The fly was observed in the laboratory to emerge through the circular disc of the pupa at its anterior end by lifting it up. Under field conditions the

freshly emerged flies were found crawling on the infested plants or on the ground with wings not fully extended. Three pairs of black spots on the abdomen were quite distinct. The adult rested or walked about for 10-12 minutes, moved the wings and legs continuously and got the wings cleared and stretched over the abdomen. The colour of the abdomen changed to pale pink and the fly in general turned grey. The fly then made slight but rapid movements over the leaf surface or on the ground and took to flight.

The flies were very active with positive phototropic behaviour. The females were bigger in size than the males. The trifoliate process of the male was visible to the naked eye at the time of emergence from pupa which was folded into the abdomen before the fly flew away.

The emergence of flies from 100 field collected pupae was found to be 86, out of which 46 were females and 40 males, the sex ratio being 1.15:1.

Flies that emerged under laboratory conditions, did not show tendency for mating and thus laid no eggs, but the field collected flies were found to lay eggs on seedlings inside the cages. However, at Hyderabad flies were observed to mate in rearing cages and were found to lay eggs on sorghum seedlings provided in the cage. One fly on an average was recorded to lay 27 eggs when fed on glucose and brewer's yeast. The longevity of adults was recorded to be 6-7 days in captivity.

ENTOMOLOGY

2. Behaviour

The behavioural studies on various aspects of adults and larvae of sorghum shoot fly were conducted during different periods and the results are presented here.

(a) Adult

(i) Feeding behaviour : The feeding behaviour of sorghum shoot flies was observed under artificial and field conditions. The flies, in rearing cages were fed on glucose solution, dry glucose powder and brewer's yeast and it was found that they were attracted more towards yeast. Under field conditions flies were observed to feed on honey dew.

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(ii) Mating behaviour : The observations on the mating behaviour of shoot flies were made inside the rearing cages at Hyderabad during July, 1971. Flies when fed on glucose and brewer's yeast were found to get stimulated and perform copulation 1-3 days after emergence. The female usually rested on the leaf surface and the male played the active role. Bright morning sunshine between 0900-1100 hours was found favourable. The male approached the female, with its wings vibrating, from the front and occasionally touched the female with its proboscis. Male was seen to produce mounds of white foam and the female was found often feeding on it. The male moved about and then was seen to come closerto the female, keeping wings

quivering, touching its proboscis to the thoracic region of its partner, with abdomen bent to one side and the trifoliate bristle unfolded. It tried to leap on the female which often repelled and many a times the female flew away from the site. But the male with its fast turning on the back of female for copulation was noticed after about 10-15 minutes. It was also observed that if one female flew away and another started feeding on the mount of white foam, the male attempted to approach the second one for the purpose of mating.

The female was usually found sitting when pairing but if disturbed by other males, it leaped or flew away to other seedlings. Mating lasted for 2-5 minutes. Egg laying started 1-2 days after mating.

In the field, males were observed to behave in the similar way as under laboratory conditions. However, the actual pairing could not be observed.

(iii) Oviposition behaviour : The observations on the process of oviposition were recorded at Hyderabad, inside the rearing cages. At the time of egg laying, a female was observed to survey a few plants with fast movements and then selected a suitable site on the underside of leaf blade, for oviposition. It was seen that the fly rested there, with its head towards the leaf apex and the ovipositor touching the leaf surface. The fly gave a jerk to the abdomen, twisted the body three to four times and

threw out the egg gently by contracting the ovipositor. The whole process of egg laying took half to one minute and the fly took to flight soon after depositing the egg.

Eggs were deposited on the underside of the leaf, oriented in parallel to the leaf veins. During egg laying the gelatinous secretion was not visible but the egg appeared to be wet with glair, which soon disappeared.

Time of oviposition : The observations on the number of eggs laid at different hours of the day were recorded during April and September, 1972, the two peaks of fly activity. The data on egg count on three to four leaf stage seedlings in April and 2-4 leaf stage seedlings in September are presented in Table 6.

Table 6

Number and percentage of eggs laid during different hours of the day by sorghum shoot fly, Atherigona soccata

Time of observation	Number of eggs laid		%age of oviposition	
	April	September	April	September
0600 hrs	1	4	3.12	3.33
0800 hrs	14	58	43.75	48.33
1000 hrs	9	33	28.15	27.50
1200 hrs	3	8	9.37	6.66
1400 hrs	0	0	0.00	0.00
1600 hrs	1	3	3.12	3.33
1800 hrs	4	3	12.50	2.50
1900 hrs	-	3	-	2.50

A perusal of the data in Table 6 reveals that more number of eggs were laid in the morning, from 0600 to 0800 hours (43.75 to 48.33 per cent) and from 0800 to 1000 hours (27.50 to 28.15 per cent) both in April and September, very few eggs or no eggs were laid during the hot hours of the day. However, a good number of eggs was laid again in the evening hours. No egg laying was found to occur during the night, though a small number of eggs was observed to be laid at dawn during both the months.

Preference for seedling stage : Preliminary studies conducted in September, 1971 showed that the shoot fly preferred three and four leaf stage seedlings for oviposition. To confirm this and also to obtain further information on seedling stage preferred for egg laying, detailed experiments were conducted in April and September, 1972. In April, potted seedlings of different leaf stages were exposed, all at one time, to natural fly population for oviposition, whereas in September, plants were grown in the field and the observations on seedlings for oviposition were recorded as they progressed in growth from one leaf stage to another. The data on the eggs laid on different leaves at different leaf stages of seedlings are presented in Tables 7 and 8.

It is evident from the data in Table 7 that shoot fly laid eggs on the seedling of cotyledonary leaf stage to six leaf stage, whereas no egg was laid on

Table 7

Oviposition preference of sorghum shoot fly, Atherigona soccata for different leaves and leaf stages of sorghum during April, 1972 (Mean of 30 plants-10 replications)

Leaf stage of seedlings	Number* of eggs laid on different leaves										Ovi-position (%)
	Coty.	1	2	3	4	5	6	7	8	Total	
Cotyledonary	1									1	0.7
One	2	7								9	6.4
Two	0	4	10							10	10.0
Three	0	0	5	31						36	25.7
Four	0	0	1	16	33					50	35.7
Five	0	0	0	1	9	8				18	12.0
Six	0	0	0	0	2	7	2			11	7.0
Seven	0	0	0	0	0	1	0	0		1	0.7
Eight	0	0	0	0	0	0	0	0	0	0	0.0
Total	3	11	16	48	44	16	2	0	0	140	

* Figures rounded off.

the seedlings of seven or eight leaf stages. The four leaf stage seedling showed the highest deposition of eggs (35.7%), followed by three leaf stage (25.7%). The extent of oviposition was reduced on five and six leaf stage seedlings to 12.0 and 7.0 per cent respectively. A negligible number of eggs was recorded on cotyledonary leaves of very young plants. In seedlings of two leaf stage, oviposition occurred on first and second leaves. Similarly in three leaf stage seedlings, fly preferred to oviposit on young fully exposed second and third leaves.

So was the case with four leaf stage seedlings, where young topmost fully exposed leaves collected highest number of eggs (33). The trend was found to be a little changed in five or six leaf stage seedlings in that the youngest leaf of the whorl received comparatively less number of eggs. No egg was found on seventh or eighth leaves. It is also evident from the table that on the whole, third and fourth leaves were oviposited maximum eggs being 48 and 44 respectively.

Table 8

Oviposition preference of Atherigona soccata Rondani at different age and leaf stages of sorghum during September, 1972 (Observations on 100 seedlings)

Leaf stage of seedlings	Number of eggs laid on different days after germination									Oviposition (%)
	1	4	7	10	15	20	25	30	Total	
One	2	6	1	0	0	0	0	0	9	4.7
Two		8	16	3	0	0	0	0	27	14.2
Three			36	18	7	0	0	0	61	32.1
Four				28	22	7	1	0	58	30.5
Five					18	9	3	1	31	16.3
Six						2	2	0	4	2.1
Seven							0	0	0	0.0
Eight								0	0	0.0
Total eggs	2	14	53	49	47	18	6	1	190	

The data of the field experiment in the above table show that oviposition started soon after the

emergence of seedlings, which continued up to 25 days after germination or till the plants attained seven leaf stage. As the plant grew, the activity of flies for oviposition was shifted to the next fully exposed young leaves and it continued till the plants reached four leaf stage. In two-week old seedlings, oviposition of eggs was less on fully exposed fifth leaf (18) as compared to that on the fourth leaf (22). Similar was the case with 20 or 25 days old seedlings.

In this experiment also the flies preferred three and four leaf stage seedlings for oviposition and as many as 32.1 and 30.5 per cent eggs were laid on these seedlings. No egg was observed on seven or eight leaf stage seedlings.

The oviposition behaviour of shoot fly was found to be greatly influenced by the irrigation. The egg count increased significantly soon after irrigation in the field. Three leaf stage 25 seedlings in flats (lying in sorghum field) though sprinkled water daily, received six eggs in 24 hours preceding to general field irrigation as compared to 24 eggs in one day after irrigation. The results were very much conspicuous during summer months.

The number of eggs recorded per leaf/plant was usually more than two during the peaks of fly activity and as many as 12 eggs were counted on one plant during September. In general, it was observed that shoot fly laid eggs on the underside of young leaves, at the basal half of lamina, oriented parallel to leaf veins. But in exceptional

cases, eggs were found on dorsal side of leaf, at the apex of leaf blade or laid not parallel to leaf veins.

(b) Larva

(i) Penetration behaviour : Observations based on thirty-nine maggots seen hatching and penetrating into the plant tissue, under field conditions, are presented here. Egg hatching took place in the morning between 0600-0800 hours (Table 3). The tiny larva appeared with its blackish anterior end by rupturing the dorsal side of the egg shell. In 2-3 minutes it came out and crawled freely. It rested for a while here and there but then started moving slowly detecting its path and within 15 minutes moved 2-3 cm towards the leaf base. It then creeped downward along with the leaf margin. It was observed to retreat immediately if turned towards apical portion of leaf. In some cases it shifted even to dorsal side of the leaf but usually travelled along the leaf margin. It then crossed the leaf auricle and ligule from the side instead of boring through it.

Presence of dew droplets on leaves was found to enhance the maggot's movement. The water droplet, present at the leaf axis, further activated the larva and it then penetrated in between the leaf sheath and plant axis. However, the excess of dew water droplets, in a few cases, was found unsuitable for the tiny maggot, where it struggled for 2-5 minutes before making a successful

penetration. The larva while on the leaf blade was also found sometimesto nibble the tissues and make a fine 2-3 mm streak. Usual time taken by the maggot from emergence to entering between leaf sheaths was recorded to be 30-50 minutes.

On opening and unfolding the leaf sheaths of affected seedlings 4-6 hours after maggot penetration, the inner path was studied. Usually no apparent symptoms were visible but in a good number of seedlings the prominent streak of feeding by nibbling was noticed on the inner folds of the sheath of leaf from where it entered. The soft infolded leaf lamina was also found nibbled in a few seedlings.

It was observed that the larva generally penetrated down into the seedling between the leaf sheath of leaf on which it emerged and the plant axis. In some of the seedlings it was also seen that the maggot after reaching the leaf axis moved upward and penetrated through the leaf sheath of the next leaf and the plant axis. Penetration of tiny maggot was also observed to take place through the folds of the whorl.

(ii) Feeding behaviour : Maggot after reaching the base, a few (5-8 mm) millimetres above the nodal end of the oviposited leaf, was observed to bite through the soft tissues (parenchyma cells) of the next leaf sheath and made a horizontal cut. Generally, this cut was not

complete and it was observed that three fourth of the sheath was severed. Maggot then found its way in and destroyed the central core and continued feeding on the most delicate and soft tissues in the basal portion, 5-10 mm above the growing point. In most of the seedlings, the growing point was found intact even after six hours of larval penetration. Seedlings when dissected after 30 hours of egg hatching, showed complete destruction of growing tip. First instar maggots moulted in 36-48 hours and exuviae were found in pale brownish tissues 5-10 mm above the growing point.

Second instar larva was seen to feed in the middle portion of the plant, 2-4 cm above the growing point, on the soft fresh or semi-rotten tissues. The head of the maggot was usually upward. Exuviae of second moult were also located in this region in semi-rotten tissues.

Third instar larvae were found to feed up and down from the base to the funnel portion, on the folded leaf lamina of affected leaves, forming the 'dead hearts'. Maggots were observed even to eat away the tissues below the meristem, bore a tunnel downward to get escaped into the soil.

The observations presented in Table 9 further reveal that the first instar larvae were present in fresh tissues and the second instar larvae were located either in the fresh or semi-rotten tissues of affected leaves. The

third instar larvae were observed to move freely and rapidly in the tissues.

Table 9

Penetration behaviour and location of larvae of Atherigona soccata in sorghum (during April, 1973)

Oviposition on leaf	Horizontal cut at the leaf sheath of	Larval instar observed	Site of larva in plant tissues
Second	Third	Third	Semi-rotten
Second	Third	First	Fresh
Third	Third(funnel)	Second	Fresh
Third	Fourth	Second	Semi-rotten
Second	Third	Third	Rotten
Third	Fourth	Third	Rotten
Second	Fourth(funnel)	Second	Fresh
Second	Third	Third	Fresh
Third	Fourth	Second	Semi-rotten
Third	Third(funnel)	Third	Fresh
Third	Fourth	First	Fresh
Third	Fourth	Third	Semi-rotten

Following observations further indicate the nature of plant tissues on which different instars of larvae were found feeding. The first instar larva was mainly found feeding on soft tissues soon after its penetration and reaching the growing point and it was observed that rotting of tissues at the base started two

days after initial injury and by this time the first instar was observed to be over.

The first instar larva was manipulated in many ways. The tiny maggot picked up from the leaf surface, when transferred to the whorl of the same plant, it travelled down and caused 'dead heart' symptoms. The young maggot, 30 hours after its feeding, when put into the whorl of healthy, 2-3 leaf stage seedlings, was noticed to cause usual damage but two days old larvae sometimes failed to do so.

Second instar larvae also behaved in the similar way but the success obtained in establishing them on healthy tissues was comparatively low. Three days old larva (one day old second instar) was seen to cause 'dead heart' and grew to third instar while 4 or 5 days old maggots failed to cause a 'dead heart'.

Third instar larvae when put in the funnel of healthy leaves, immediately descended and were noticed to cause withering of the youngest leaf within few hours. The newly transformed third instar was observed to cause 'dead heart' symptoms but the full grown maggots caused leaf injury which became quite conspicuous on its emergence. The full-fed maggot did not prefer to pupate in such plants and it was observed to come out.

In laboratory tests, different instars of shoot fly larvae were offered rotten (six days old 'dead

heart') tissues and semi-rotten (2-3 days old 'dead heart') tissues of sorghum CSH-1. It was observed that the tiny maggot when released on semi-rotten food, died after 3-4 hours but did not survive for more than one hour in completely rotten tissues. The newly moulted second instar larva survived for 10 hours or more in semi-rotten tissues and for 2-4 hours in rotten tissues. Third instar larva reached pupation when fed on semi-rotten tissues but died after 24 hours when released on completely rotten 'dead heart' material. On the contrary, the larvae of scavenger flies pupated successfully on partially and completely rotten tissues but failed to survive on fresh inner folds of leaves, though they made some nibbling in the soft part of leaf lamina.

Larval migration : It was observed that the third instar larvae migrated or shifted frequently from the main shoot to one of its tillers. It was usually common in the seedlings where the infestation started at first or second leaf stage and the maggot continued to feed all along the funnel. In the mean time, the tiller which developed at the base, emerged through the leaf sheath and the maggot shifted from main shoot to the growing tiller. In some cases, tiller was attacked before it emerged. The maggot then completed its remaining stage on the growing tissues of tillers. The maggot entered the tillers always through the funnel and never through the basal portion.

Maggots collected from the 'dead hearts' and then released into the funnel of seedling or tiller, also behaved in the same way.

Dissection of plants showing 'dead hearts' revealed that the inner soft and fresh tissues were completely consumed. The maggot even ate away the tissues below the growing point. These observations reveal that the larvae migrated for want of food and thus shifted to tillers. Out of 65 potted seedlings, maggots were recorded to shift from 'dead hearts' to tillers in eleven cases.

Generally, a single larva was found per damaged shoot but very often two or more maggots were also noticed. In such cases the maggots of younger instars were located in the leaf folds of affected leaves, whereas those of second and third instars were located in the basal portions of the damaged shoot.

Nature of attack : The external symptoms on the affected seedlings appeared a few hours after the penetration of maggot of shoot fly. As a result of horizontal cut at the base and subsequent feeding, the tip portion of central emerging leaf was affected within three to four hours of attack, tip margin got folded inwardly and its terminal point drooped. During the next 3-6 hours, it was seen that the leaf margin further folded inwardly and wilted. Colour turned slightly ashy green and gave a dull appearance.

Table 10

Appearance of symptoms of shootfly attack on sorghum seedlings

Site of oviposition (leaf)	Leaf stage of seedling	Time taken for Withering of central leaf (hours)	Time taken for 'dead heart' formation (days)	Leaf (leaves) forming 'dead heart'
Third	3	6	2	Fourth
Second	3	8	2	Third & fourth
Third	3	8	3	Fourth & fifth
Third	3	6	1	Fourth
Third	3	10	1	Fifth
Second	4	8	2	Fourth & fifth
Fourth	4	6	2	Fifth
First	2	6	1	Second
Fourth	4	6	1	Fifth
Fifth	6	12	2	Sixth
Second	2	6	1	Third & fourth
Third	3	6	2	Fourth
Third	4	8	2	Fifth
Second	3	6	2	Fourth
Third	4	8	2	Fourth & fifth
Third	4	10	2	Fourth & fifth
Second	4	10	2	Fourth
Third	4	8	2	Fourth & fifth
Third	4	6	2	Fourth
Fourth	4	6	1	Fourth

Withering of plants started six hours after attack (Table 10) where either the plant was too young (2-3 leaf stage) or the egg was deposited on the leaf in the whorl. The time needed for causing withering of central leaves after larval entrance was 6-10 hours; more

time was required to show injury symptoms where either the affected seedling was well grown (in 5-6 leaf stage) or the larva entered in unusual way. Within 12 hours of attack, complete withering of central leaves was recorded in all the cases.

The central leaves dried completely and 'dead hearts' were formed in 1-2 days. The exposed part of affected leaves got twisted (Fig. 5) but the lower portion near the funnel did not dry and remained partially green or greenish yellow. At this stage the 'dead hearts' could not be pulled out with slight pressure. After four to five days of attack, 'dead hearts' gave a distorted look and could be pulled out easily with slight pressure.

Dissection of the affected seedlings at different intervals showed that the internal tissues started rotting 48 hours after the maggot invaded the growing point. The tissues then turned pale brownish to light brown during the next 24 hours and on the fourth day the tissues turned brown. Six days after the initial injury the lower portion of the sheath turned dark brown, became putrid and watery. While making these observations, the instars of larvae were also noticed. First instar larva was found before the tissues turned brownish but second instar larva was obtained when tissues inside turned light brown or brown. However, the third instar (full grown) larva was obtained when the lower portion of 'dead heart' started putrefying.

Fig. 5. Sorghum seedlings showing 'dead heart' formation

a. Healthy
b. Affected

3. Seasonal incidence

The seasonal incidence of sorghum shoot fly was recorded on sorghum hybrid CSH-1 for three years and the data with respect to the number of eggs laid and the number of plants forming 'dead hearts' are presented in Appendix III and Table 11 (Fig. 6).

The perusal of the data reveals that shoot fly incidence was prevalent during all the twelve months of the year but with varying intensity. With the warming of weather, there was a sharp rise in fly activity in March, 1971 and the rate of oviposition was also so high that it caused 72.1 per cent 'dead hearts' in April. Similar were the observations recorded in other years. The fly activity got reduced instantaneously with the approach of hot dry conditions and a sharp decline of fly incidence was observed in June. The continuous rains during July obstructed the fly activity but it was again resumed by the middle of August.

A second peak of fly activity was observed during September in all the three years of study. The percentage of 'dead hearts' formed in September even exceeded those recorded in April. There was a decline in fly activity in October and November, whereas in December an appreciably low fly activity was recorded on tillers or on seedlings in flats.

Table 11

Average number of eggs laid and 'dead hearts' caused by Atherigona soccata Rondani on sorghum hybrid CSH-1 sown at weekly intervals for three years at Ludhiana

Month	1971		1972		1973	
	Number of eggs laid per plant	Percentage 'dead hearts' formed	Number of eggs laid per plant	Percentage 'dead hearts' formed	Number of eggs laid per plant	Percentage 'dead hearts' formed
January	-	-	-*	-*	0.03	6.4
February	-	-	0.37	20.0	0.04	10.3
March	-	41.2	0.99	51.1	0.63	56.6
April	-	72.1	2.01	62.9	1.86	73.6
May	-	39.0	0.58	36.1	0.54	41.1
June	-	10.0	0.16	21.0	0.16	14.3
July	0.22	22.3	0.24	23.0	0.32	18.4
August	0.85	38.0	0.77	37.8	0.56	39.4
September	2.56	82.6	2.00	75.5	1.94	77.3
October	0.94	68.5	0.82	58.9	1.35	57.3
November	0.24	20.0	0.16	22.4	0.43	42.8
December	0.08	18.3	0.04	13.1	0.11	18.3
'r' values	0.3975		0.3541		0.3733	

* No germination of Sorghum in the field

- Data not recorded

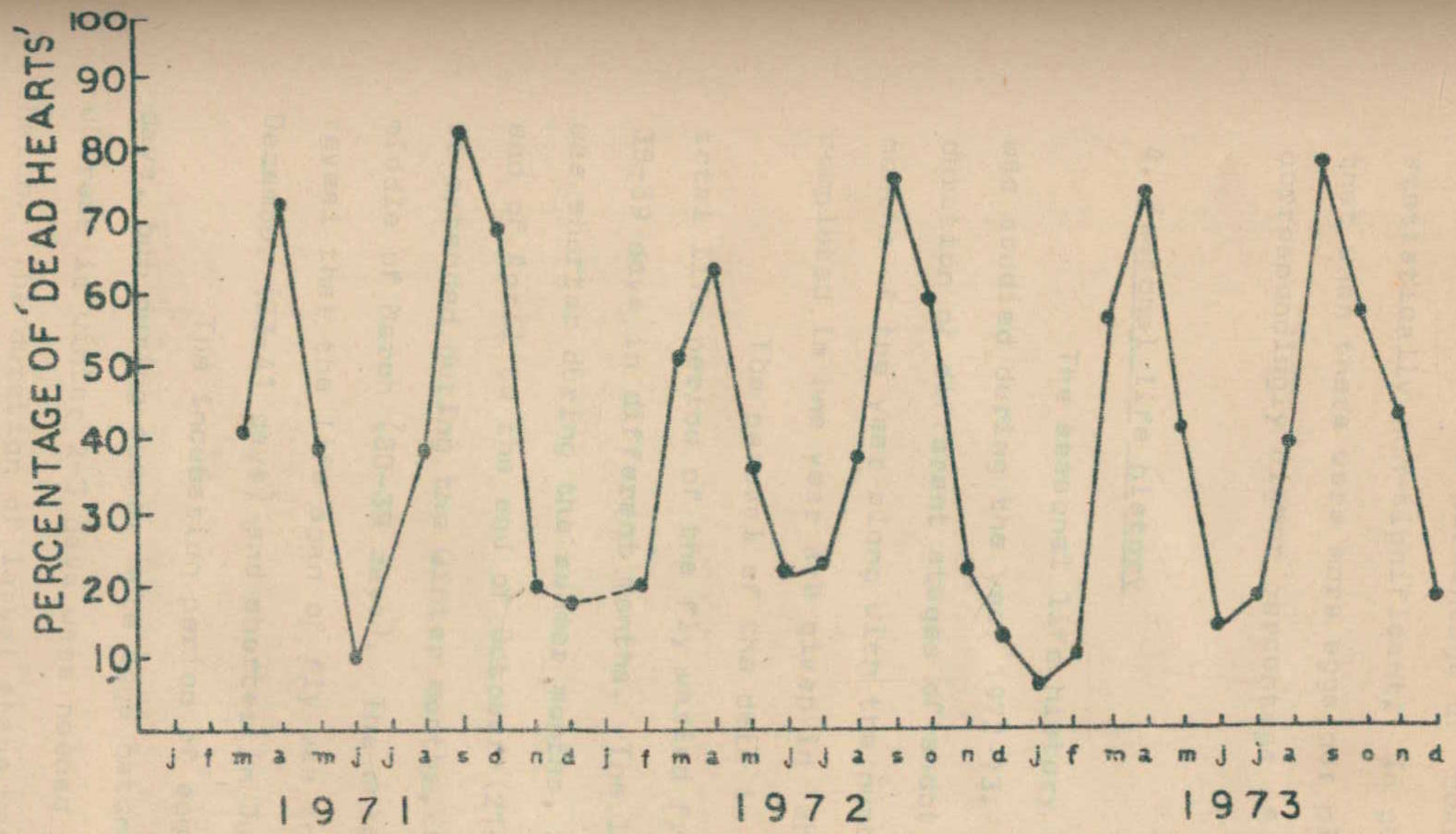

FIG.6. SEASONAL INCIDENCE OF SORGHUM SHOOT FLY, ATHERIGONA SOCCATA RONDANI AT LUDHIANA DURING 1971–1973

The correlation between the number of eggs laid per plant and the percentage of 'dead hearts' formed was statistically non-significant. In general, the trend was that when there were more eggs per plant, there was correspondingly higher percentage of 'dead hearts' formation.

4. Seasonal life history

The seasonal life history of sorghum shoot fly was studied during the year 1972-73. The data on the duration of different stages of shoot fly in different months of the year along with the number of generations completed in one year are given in Tables 12 and 13.

The perusal of the data in Table 12 shows that the total life period of the fly varied from 21-22 days to 38-39 days in different months. The life span of the fly was shorter during the summer months, starting from the end of April to the end of October (21-25 days), whereas it extended during the winter months, from November to middle of March (30-39 days). The data in Table 13 also reveal that the life span of fly was the longest in December (33-41 days) and shorter in June (19-24 days).

The incubation period of eggs varied from 1-3 days, but during summer more eggs hatched in 1-2 days, whereas in winter 2-3 days were needed for the eggs to hatch. The duration of larval stage was observed to vary from 9-21 days with marked variations during different

Table 12

Duration of stages in life cycle of sorghum shoot fly, Atherigona soccata Rondani and its number of generations at Ludhiana during 1972-73

(Observations on 10 infested seedlings)

Dates of				Average duration (days)				Total life period (days)	Number of generations
Sowing	Germination	Oviposition	Adult emergence	Egg	Larva	Pupa	Adult*		
23. 8.72	26. 8.72	7. 9.72	25. 9.72	1.5	9	7	6	23-24	One
14. 9.72	18. 9.72	28. 9.72	21.10.72	1.5	10.5	7	6	25	Two
11.10.72	16.10.72	24.10.72	20.11.72	1.5	15	7	7	30-31	Three
11.11.72**	16.11.72	23.11.72	22.12.72	2	17	8	7	34	Four
10.12.72**	16.12.72	26.12.72	25. 1.73	2	20	8	8	38	Five
12. 1.73**	18. 1.73	29. 1.73	14. 2.73	2	21	8	8	39	Six
3. 2.73**	9. 2.73	18. 2.73	11. 3.73	1.5	17	8	7	33-34	Seven
26. 2.73	5. 3.73	14. 3.73	4. 4.73	1.5	11	8	7	27-28	Eight
21. 3.73	26. 3.73	7. 4.73	26. 4.73	1.5	10	7	6	24-25	Nine
18. 4.73	23. 4.73	29. 4.73	19. 5.73	2	11	7	4	24	Ten
9. 5.73	13. 5.73	22. 5.73	11. 6.73	2	10.5	7	4	23-24	Eleven
30. 5.73	4. 6.73	14. 6.73	3. 7.73	2	11	7	4	24	Twelve
20. 6.73	30. 6.73	6. 7.73	23. 7.73	1.5	9	6	5	21-22	Thirteen
13. 7.73	17. 7.73	26. 7.73	13. 8.73	1.5	9	7	6	23-24	Fourteen
3. 8.73	7. 8.73	16. 8.73	3. 9.73	1.5	9.5	7	6	24	Fifteen***
21. 8.73	27. 8.73	6. 9.73	24. 9.73	1.5	9	7	6	23-24	Dne
14. 9.73	19. 9.73	27. 9.73	22.10.73	1.5	10.5	7	6	25	Two
12.10.73	19.10.73	26.10.73	23.11.73	1.5	15	7	7	30-31	Three
2.11.73	13.11.73	26.11.73	26.12.73	2	17	8	7	34	Four

* Adult longevity under laboratory conditions.

** Sorghum seedlings raised in flats, were used.

*** Number of generations in one year (September, 1972 to September, 1973).

months. Larval duration appeared to vary from 9 to 11 days during most of the months but in the winter months it increased steadily to 17-21 days. Pupal stage was completed in 6-8 days throughout the year.

Table 13

Duration of different life stages of sorghum shoot fly in different seasons of 1973

Month	Duration (in days)				Total life period (in days)
	Egg	Larva	Pupa	Adult*	
March	1-3	9-12	6-8	5-7	21-30
June	1-2	8-10	6-7	4-5	19-24
September	1-3	9-11	7-8	6-7	23-29
December	2-3	17-21	7-8	7-9	33-41

*Adults reared and kept in small cages for longevity

The adults did not survive for long at room temperature when kept under captivity. High temperature of summer months further restricted the survivial period to four days. However, in winter months adult longevity increased to 7-9 days.

The life cycle of shoot fly was studied, one generation after the other, under field conditions. Fifteen generations were completed in one year from September, 1972 to September, 1973.

During the course of study of life cycles of shoot fly, the behaviour of larva to select the site for

Table 14

Larval selection of site for pupation during different seasons of 1973 (Observations on 25 seedlings)

Month	Larvae (Living or dead)	Pupation site		
		Basal portion	Leaffolds	Shifted to soil
March	6	8	10	1
June	9	2	13	1
September	11	3	1	10
December	9	2	0	14

pupation, was found to be different during different seasons. The information in Table 14 shows that during March, the full grown larva preferred the basal portion and the leaf folds of affected plants for pupation. During June, the larval tendency was to pupate more in rotten tissues of leaf folds than at the base. During September and December, however, a majority of the larvae shifted to the soil for pupation.

B. Host non-preference studies for oviposition

The promising lines of sorghum were tested for the non-preference of Atherigona soccata for oviposition and results are presented in Table 15.

The data reveal that the eggs were mostly laid on the second and third leaves, though some eggs were also laid on the first and fourth leaves. Among different varieties, lesser number of eggs (2-4) was laid on IS 5604,

Table 15

Preference/non-preference of *Atherigona soccata* for oviposition on different leaves of different sorghum varieties tested during September, 1971 (5 Replications)

Varieties	Number of eggs laid on different leaves							Number of plants		
	1st	2nd	3rd	4th	5th	6th	Total	With eggs	With 'DH' formed	Recovered from 'DH'
IS 1054	0	3	2	0	1	0	6	4	3	-
IS 2123	1	2	2	0	0	0	5	4	4	1
IS 4476	1	3	2	2	-	-	8	5	5	-
IS 4567	2	2	1	1	-	-	6	5	5	-
IS 5072	3	4	-	-	-	-	7	5	5	1
IS 5383	0	5	2	0	0	0	7	4	4	-
IS 5469	0	3	3	1	-	-	7	5	5	-
IS 5470	1	1	1	0	0	0	3	2	1	-
IS 5566	0	2	2	0	0	0	4	4	3	1
IS 5604	0	0	1	1	0	0	2	1	1	1
IS 5622	0	1	1	0	0	0	2	2	2	-
IS 8315	1	1	4	1	-	-	7	5	3	-
Swarna	1	3	5	-	-	-	9	5	5	-
CSH-1	1	3	4	1	-	-	9	5	5	-

'DH' 'Dead hearts'

- No record of observation after 'dead hearts' formation in all the plants.

IS 5622, IS 5470 and IS 5566. More eggs (5-8) were laid on all other lines tested. However, on susceptible checks 9 eggs were observed.

The extent of 'dead heart' formation was also variable in different varieties. Minimum 'dead hearts' were formed in IS 5470 followed by IS 5622, IS 5566, IS 1054, IS 8315 and IS 2123. In all other varieties complete destruction of main shoots was observed. A few plants in IS 5604, IS 5566, IS 2123 and IS 5072 showed recovery from 'dead hearts' (Fig. 7 a&b).

On the other hand, in susceptible checks (Swarna and CSH-1), the number of eggs laid was much higher (9) and all the plants bearing eggs resulted into 'dead heart' formation, which did not recover.

From these studies it appeared that sorghum lines IS 5604, IS 5622, IS 5470 and IS 5566 were less preferred for oviposition. It also shows that in lines IS 1054, IS 5470, IS 5566, IS 5604 and IS 8315, some of the plants with eggs remained unaffected.

Observations of the field trial on selected lines of sorghum for non-preference for oviposition are incorporated in Table 16.

All the lines and varieties of sorghum exhibited a highly significant difference in the number of eggs laid, number of plants with eggs and the number of 'dead hearts' formed. IS 5622 was least preferred for oviposition, less

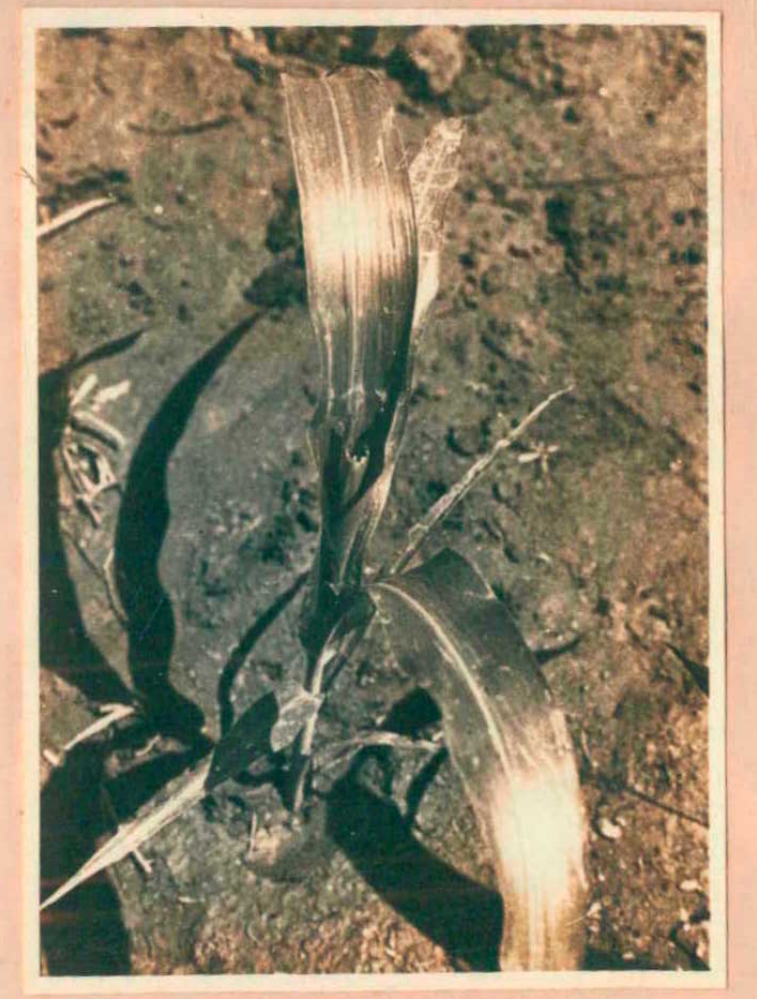

Fig. 7. Seedlings of resistant sorghum lines showing recovery from shoot fly attack

(a) IS 5072

(b) IS 5604

Table 16

Non-preference of shoot fly, Atherigona soccata, for oviposition on promising lines/varieties of sorghum.

(Mean of 3 replications each having 20 seedlings)

Lines/varieties	Number of eggs laid	Number of plants with eggs	Number of 'dead hearts'
IS 1054	11.3	7.7	6.7
IS 2123	7.3	6.7	5.7
IS 5383	4.3	4.0	4.0
IS 5470	6.7	5.7	2.7
IS 5566	5.3	4.0	2.3
IS 5604	8.3	7.3	5.3
IS 5622	2.7	2.7	2.3
Swarna	28.0	19.0	18.0
CSH-1	35.0	18.7	18.3
CSH-3	57.0	18.3	17.7
C.D. at 5%	6.53	3.58	3.86
C.D. at 1%	8.95	4.91	5.29

Analysis of variance (MSS)

Source	d.f.	Number of eggs laid	Number of plants with eggs	Number of 'dead hearts'
Replication	2	1.05	1.05	4.90
Varieties	9	954.60**	128.98**	140.76**
Error	18	14.59	4.36	5.08

plants were involved in oviposition and only a few 'dead hearts' were formed as compared to other lines. The susceptible checks (Swarna, CSH-1 and CSH-3) had high preference for oviposition.

C. Antibiosis studies in different promising varieties of sorghum

With a view to finding out the antibiosis phenomenon of resistance to Atherigona soccata Rondani, the promising lines of sorghum were tested under natural conditions, to know their effect on different stages of life of the fly. The data recorded on the duration of egg, larvopupal period and adult longevity as influenced by different lines and cultivars of sorghum, are elucidated in Table 17.

Table 17

Duration of different stages of shoot fly as influenced by promising lines and cultivars of sorghum

Line/variety	Duration of different stages (days)					
	Egg	Larvopupa	Adult*	Total	Pupa	Larva
IS 1054	2	17-18	2-3	21-23	8	9-10
IS 2123	2	19	3	24	8	10
IS 5470	1-2	17-20	3	21-25	8	9-12
IS 5566	2	21-25	2-3	25-30	8-9	13-16
IS 5604	2	20-21	2-3	24-26	8	12-13
IS 5622	1-2	19-20	3-4	23-26	8	11-12
Swarna	2	15-17	5	23-24	7-8	8-10
CSH-1	1-2	15-18	6-7	22-28	7-8	8-10

*Adults were fed on glucose and brewer's yeast in captivity

The perusal of the data in Table 17 shows that the lines or cultivars had no effect on the incubation period of egg and it hatched in 1-2 days on all the seedlings. There appeared to be an appreciable variation in the larvopupal duration in different lines and cultivars. After subtracting the pupal period, larval duration was found to be substantially longer in IS 5566 and IS 5604 being 12-16 days as compared to that in the most popular cultivars like Swarna and CSH-1 (8-10 days). In other lines (IS 5470 and IS 5622) the larval life was also prolonged by 1-3 days. No appreciable change in pupal period was recorded in any of the lines tested.

The adults obtained from each line and cultivar when kept in small cages or jars (20 x 15 cm) died without mating/laying eggs. As such the adults emerging from the promising lines lived for 2-3 days. However, the longevity of adults was 6-7 days in those obtained from susceptible checks.

Observations on the time taken for the appearance of shoot fly damage symptoms in promising lines and cultivars of sorghum are given in Table 18. It was observed that the withering of central leaf (leaves) appeared mostly 24-36 hours after the maggot penetration in resistant lines and after 6-12 hours in the susceptible checks. Similarly the 'dead heart' injury became conspicuous after 2-3 days in resistant lines and in 1-2 days in Swarna or CSH-1. It

reveals that the larva took more time to sever the resistant plants at the base than the susceptible ones.

Table 18

Time required for shoot fly, Atherigona soccata, damage symptoms in promising varieties of sorghum

Varieties	Time taken for	
	Withering of central leaf (in hours)	'Dead heart' formation (in days)
IS 1054	24-36	2
IS 2123	10-24	1-2
IS 5470	24	2
IS 5566	24-36	2
IS 5604	24-36	3
IS 5622	24	2
Swarna	10-12	1-2
CSH-1	6-10	1-2

In order to investigate the mechanism and basis of resistance to shoot fly, studies on lines IS 5470, IS 5566 and IS 5604 and susceptible checks (Swarna and CSH-1) were conducted. Observations were made on the silica bodies present in the third, fourth and fifth leaf sheaths. The data are presented in Table 19.

It was observed that the density of silica bodies, both dumb-bell shaped and irregular, was low in the third leaf sheath, more in the fourth leaf sheath and highest in the fifth leaf sheath of all the five varieties

Table 19

Mean density of silica bodies in the sheaths of third, fourth and fifth leaves of different sorghum varieties

Varieties	Dumb-bell shaped bodies (mean* No./mm^2)				Irregular shaped bodes (mean* No./mm^2)			
	3rd leaf sheath	4th leaf sheath	5th leaf sheath	Mean	3rd leaf sheath	4th leaf sheath	5th leaf sheath	Mean
IS 5470	54.2	66.5	91.4	70.7	2.2	3.4	5.6	3.7
IS 5566	68.0	88.6	100.0	85.5	6.2	8.6	15.6	10.1
IS 5605	52.2	74.2	92.2	72.8	3.2	6.4	11.2	6.9
CSH-1	22.4	31.0	35.0	29.5	1.2	1.8	2.4	1.8
Swarna	19.4	29.4	36.2	28.3	0.0	1.6	2.4	1.0

* Mean of five observations

of sorghum tested. However, the mean density of dumb-bell shaped silica bodies was found to be highest in IS 5566 (85.5/mm^2). In other two resistant lines IS 5604 and IS 5470, the density of these bodies was 72.8/mm^2 and 70.7/mm^2 respectively. On the other hand, the density of such bodies was very low in susceptible Swarna (28.3/mm^2) and CSH-1 (29.5/mm^2).

Similarly the density of irregular shaped silica bodies was very high in resistant lines being 10.1/mm^2, 6.9/mm^2 and 3.7/mm^2 in IS 5566, IS 5604 and IS 5470 respectively. In susceptible checks the density was very sparse with 1.0 particles/mm^2 in Swarna and 1.8 particles/mm^2 in CSH-1.

The pattern of distribution of silica bodies in the leaf sheath also showed variations in the resistant and susceptible varieties. The dumb-bell shaped silica bodies were distributed in regular bands each having 3-5 chains of silica bodies in resistant lines with irregular shaped bodies unevenly distributed in between the two bands. In case of susceptible checks each row contained 2-3 chains of silica particles. It was also seen in Swarna that the rows were apart and discontinued at the periphery of the leaf sheaths.

Chapter V

DISCUSSION

1. Life History

The life history of sorghum shoot fly has been studied by a number of workers (Ballard and Ramachandra Rao, 1924; Ponnaiya, 1951a; Swaine and Wyatt, 1954; Meksongsee et al., 1968; Kundu and Kishore, 1970; Young, 1970; Singh, 1971 and Barry, 1972 a&b) and detailed description of various stages and their characteristics have been made.

The results of the present investigations on the life history of sorghum shoot fly show that the general characteristics of different stages namely egg, larva, pupa and adult,are more or less similar in colour, shape, size and other features to those reported by earlier workers. However, the variations and special findings that have been observed during the present investigations are discussed here.

The size of the egg has been reported (Ponnaiya, 1951a; Rao and Rao, 1956; Kundu and Kishore, 1970; Young, 1970 and Singh, 1971) to vary from 1.2 to 1.5 mm in length and 0.10 to 0.33 mm in breadth. In the present studies the general size of egg was also found to fall in this

range with slight changes in size with age. The freshly laid eggs measured 1.39 x 0.29 mm on an average and the size changed to 1.39 x 0.31 mm and 1.38 x 0.32 mm after eight and 24 hours respectively of the development. The earlier workers have not noticed such minor changes in egg size, which if observed critically could be useful in differentiating the freshly laid eggs from that of the old ones. The increase in the breadth of the egg with increasing period of age could be attributed to developing embryo inside.

Although majority of theeggs hatched in 36-48 hours (Table 2), yet the incubation period varied from 1 to 3 days. Various other workers (Ballard and Ramachandra Rao, 1924; Ponnaiya, 1951a; Rao and Rao, 1956; Kundu and Kishore, 1970; Singh, 1971; Barry, 1972a and Granados, 1972) have also reported similar findings. Sandhu (1972b) has suggested that the flies mioht be withholding the eggs for different durations and laying them out at regular intervals to synchronise hatching in the morning. It is also possible that those eggs which are withheld for longer duration might take less time to hatch and vice-versa. This appears to be logical explanation for the variations observed in the incubation period of eggs.

Many workers (Blum, 1963; Meksongsee et al., 1968 and Awale, 1970) have reported egg hatching to occur during night or early morning. However, in the present

studies, eggs were found to hatch during the morning hours and never during day, evening or night time. About 92 per cent of the eggs hatched by 0800 hours. It appears that morning dew may bring about certain changes in micro-environments which may be congenial for egg hatching.

The newly emerged maggot measured 1.28 x 0.17 mm, which was slightly smaller than the egg size and it increased to 1.62 x 0.18 mm and 1.80 x 0.19 mm after ten and thirty hours respectively of feeding. Singh (1971) and Barry (1972a) reported similar information for newly emerged maggot but according to Meksongsee et al. (1968) and Kundu and Kishore (1970), the size of the first instar larva was bigger than that of the egg. From the variable size of first instar larva observed in the present study, it appears that their observations were based on the first instar larva taken from the plant tissues some time after the emergence.

Second instar larva measured 2.35 x 0.37 mm which is very much in accordance with those reported by Kundu and Kishore (1970). Singh (1971), on the other hand, reported the size to be 1.70 x 0.32 mm. This variation might be due to certain limitations in his observations.

According to different workers (Swaine and Wyatt, 1954; Meksongsee et al., 1968; Kundu and Kishore, 1970; Singh, 1971 and Deeming, 1971 & 1972), the size of third instar larva was 5 to 9 mm in length and 0.60 to 1.30 mm

in breadth, whereas in the present studies the size of newly formed third instar was 5.27 x 0.57 mm and that of the full grown larva was 8.20 x 0.80 mm. These measurements fall within the range of size of third instar larva reported by the earlier workers.

The shoot fly larva has been reported to pass through three larval instars by a number of workers (Ballard and Ramachandra Rao, 1924; Ponnaiya, 1951a; Swaine and Wyatt, 1954; Rao and Rao, 1956; Blum, 1963; Meksongsee et al., 1968; Moiz and Naqvi, 1968; Avidov and Harpaz, 1969; Awale, 1970; Young, 1970; Singh, 1971; Barry, 1972 a&b; Pont, 1972 and Granados, 1972). Kundu and Kishore (1970) have, however, reported four instars of shoot fly larva. Presently also three larval instars were observed, though the newly formed third instar larva and the full grown stage of the same instar exhibited a great variation in size. The size measurements reported by Kundu and Kishore (1970) for the third and fourth instar larvae corresponded to those of the newly formed and the full grown third instar larva in the present studies. It appears that on the basis of size differences, they have erroneously suggested the existence of an extra instar.

The total duration of shoot fly larva has been reported to vary from 6 to 15 days in India (Ballard and Ramachandra Rao, 1924; Kundu and Kishore, 1970 and Singh, 1971). In the present studies, the larval duration was

found to vary from 8-11 days with average duration of 1½-2 days, 2-3 days and 4-6 days for the first, second and third instars respectively. The duration of larval period appears to be influenced by the plant tissues available for the larva to feed.

Before the formation of pupa, the full grown larva contracted in size (4.25 x 0.91 mm) and colour changed to deep yellow or brown. Meksongsee et al. (1968) named this stage as prepupa. It lasted for 6-8 hours. The last larval skin formed the puparium (pupal covering). Pupa was reddish brown barrel shaped, measured 3.60 x 1.23 mm. The general characters of pupa are in accordance with the findings of Ballard and Ramachandra Rao (1924), Ayyar (1933), Young (1970) and Barry (1972a). The pupal stage as reported by Singh (1971) and Sandhu (1972c) also lasted for 6-8 days.

Adult emergence took place through the circular disc of pupa and it took 10 minutes or more near the site of emergence before taking to flight. Similar observations have been reported by Meksongsee et al. (1968) on the emergence of adult. It was also noticed that in male flies, the trifoliate process was extended out at the time of its emergence from pupa which was withdrawn later on.

The adult flies when released in cages, were not seen either mating or laying eggs at Ludhiana while such was not the case observed at Hyderabad. With the present limited information, it is difficult to explain the actual reasons for such failure. Singh (1971) and Barry (1972a)

had also come across with this unwilling behaviour of flies in captivity.

The adults survived for 6-7 days or less as compared to 20-40 days in South India as reported by Ponnaiya (1951a) and Soto and Laxminarayana (1971). However, under cage conditions, Kundu and Kishore (1970), Pradhan (1971) and Singh (1971) reported 7 days' adult life in North India. This variation in adult longevity is perhaps due to climatic conditions.

2. Behaviour

(a) Adult : The adult flies were attracted towards yeast in the laboratory feeding. Similar behaviour of adult was also reported by Soto and Laxminarayana (1971) and Soto (1972b). The attractant baits having yeast base may help in exploiting and killing the adults under field conditions.

Mating occurred 1-3 days after adult emergence. In mating, male played the active role; it stimulated the female with its passionate approach. After many attempts it was able to ride over the female for copulation which lasted for 2-5 minutes. Similar observations were reported by Ramachandra Rao (1924) with respect to male approaching the female. However, he reported premating period to be 5-6 days. The artificial feeding on brewer's yeast might be responsible in reducing the premating period.

For oviposition, a female, after selecting a suitable seedling, sat on the underside of fully exposed young leaf with its head towards the apex. In the process of egg laying the female twisted the body 3-4 times and by contracting the abdomen, the egg was laid gently within half to one minute which was oriented in parallel to the leaf veins. The actual process of egg laying was not reported earlier, though the orientation of eggs in parallel to leaf veins on the underside of fully exposed leaves have been observed by many workers (Ponnaiya, 1951a; Swaine and Wyatt, 1954 and Barry, 1972a).

Egg laying occurred in the morning hours with maximum oviposition between 0600-0800 hours in both the peak periods of fly activity. Negligible oviposition was observed during the day time, however, a good number of eggs was also laid in the evening hours. Similar observations have been reported earlier (Kundu and Kishore, 1970; Anonymous, 1971 and Pradhan, 1971). However, Swaine and Wyatt (1954) from Africa and Awale (1970) from Maharashtra (Rahuri) reported that eggs were laid at night and Singh (1971) observed maximum egg laying to occur in evening hours. Since the flies have positive phototropic behaviour (Soto and Laxminarayana, 1971) and are very active in the morning hours under field conditions (Ponnaiya, 1951a; Young, 1970 and Anonymous, 1971), the egg laying in the morning hours appears to be quite natural. The observations of Soto (1971a) showed that under mercury light, flies

continued to lay eggs in all the 24 hours which further indicate that the flies lay eggs when there is bright light.

Flies preferred third and fourth leaves over other leaves for oviposition and also laid maximum eggs when the plants were of three to four leaf stage or 7-10 days after germination. Similar results were reported by Rao (1954), Rao and Rao (1956), Jain and Bhatnagar (1962) and Krishnananda et al. (1970).

As reported by Rao and Rao (1956), Kundu and Kishore (1970) and Deeming (1971), it was further observed in the present studies that irrigation enhanced fly activities and more eggs were laid one or two days after irrigation; the results were more conspicuous during summer months.

(b) Larva : The newly emerging larvae have been reported to rest near the egg shell for 40-45 minutes before shifting to the leaf base (Kundu and Kishore, 1970). However, in the present study, the larva took 2-3 minutes to emerge out of the egg shell and immediately started creeping downward. The maggot usually moved along the leaf margin and took 30-50 minutes to reach the leaf base from the site of oviposition. Similar observations have been made by Ponnaiya (1951a), Swaine and Wyatt (1954), Ritcher and Rachie (1959), Blum (1963), Meksongsee et al. (1968), Kundu and Kishore (1970), Young (1970), Singh (1971) and Barry (1972a) regarding the path, the newly emerged maggots adopt for reaching the leaf base.

The larva penetrated into the plant between the leaf-sheath of the leaf oviposited and the plant axis. In certain cases, larva entered the plant through the folds of the whorl or in between the plant axis and the sheath of the leaf next to the leaf oviposited. The earlier workers have reported the penetration of larva between the plant axis and the leaf sheath (Ponnaiya, 1951a and Blum, 1963) and through the leaf whorl (Barry, 1972a). Ponnaiya (1951a) and Blum (1963) reported that the horizontal cut made by the maggots at the base was clean and complete, which resulted in the detachment of inner leaves. In the present study, it was observed that a part of the sheath remained intact at the first instance which was detached at a later stage when the larva fed voraciously.

The observations on the feeding behaviour revealed that the shoot fly larva fed on both fresh and semi-rotten tissues. Bleton and Fieuzet (1943) reported that the maggots fed on young tissues with continuous sap supply. Doggett (1970) reported the larvae to feed inside the lamina of infolded leaves. Singh (1971) also observed larvae feeding on living tissues. Many workers, on the other hand, reported that the larvae of shoot fly fed on decaying and rotten tissues (Rao and Rao, 1956; Ritcher, 1959; Meksongsee et al., 1968; Awale, 1970; Young, 1970 and Pont, 1972). These observations might be on the presence of third instar larvae in rotten tissues.

It is a well known fact that each seedling bears usually two or more eggs but only one full grown larva was obtained per seedling/shoot though there was plenty of rotten tissues to support more than one maggot.

The larvae feed on fresh tissues is indicated when different instars collected from the field and released on fresh tissues usually survived, but died when released on rotten tissues of the 'dead hearts'. As observed in some cases perhaps it is the non-availability of fresh tissues for feeding that is responsible for the migration of the larva from an affected plant ('dead heart') to its developing tiller or to other plants. Granados (1972), while rearing the sorghum shoot fly on grasses, mentioned the requirement of more than one plant and reported maggots migrating to complete their development in other plants.

The external symptoms appeared a few hours after the penetration of the maggot into the plant. Within 3-4 hours of larval penetration, the central leaf exhibited the symptoms by inward folding of the margins and drooping of the terminal point, and within 6-10 hours it showed wilting and withering. The central leaf dried completely within 12 hours and 'dead heart' formed within 1-2 days and the plant became totally damaged after 4-5 days of attack. A similar sequence of events leading to the formation of 'dead heart' after shoot fly attack has been described by Ramachandra Rao

(1924), Ayyar (1933), Ponnaiya (1951a), Blum (1963), Young (1970) and Barry (1972a).

3. Seasonal Incidence

The results of the study on seasonal incidence of sorghum shoot fly conducted over a period of three years showed that though the activity was prevalent throughout the twelve months of a year, yet it had only two peak periods of its activity, one during April and second during September.

Singh (1971) has earlier reported from Punjab that the shoot fly incidence was more in March than in April and more in October than in September. However, the findings of Sharma (1968), Jotwani et al. (1970) and Pradhan (1971) from Delhi with respect to peak periods of fly activity during March-April and September-October are similar to those of the present study. The fly activity seems to be governed mostly by the temperature prevailing in different seasons or months. From the meteorological data (Appendix I), it can be seen that mild temperatures (23.5° to 26.7°C in April and 26.7° to 28.3°C in September) and the periods after rains were conducive to high incidence of the shoot fly, while high and low temperatures (above 31.3°C in May-June and below 13.7°C in December) and dry weather were unfavourable for the fly activity. Period of kharif season (upto July) might be safe from shoot fly attack for the sowing of sorghum.

4. Seasonal Life History

The temperature, and humidity in different months, perhaps has affected the duration and behaviour of different stages of the fly. The incubation period of egg did not vary in different months, though it was slightly more in winter than in summer. The larval duration showed marked variations during different months, lasting from 9-11 days during summer and from 17 to 21 days during winter. Several workers from different places (Ballard and Ramachandra Rao, 1924; Rao and Rao, 1956; Kundu and Kishore, 1970 and Singh, 1971) have reported larval period to last for 6 to 15 days. Larva being an internal feeder appears to be influenced only by the temperature. Under laboratory conditions the larval duration was reported to be 13.5 days at 20°C temperature, which was reduced to 8.1 and 7.2 days at 25°C and 30°C respectively (Anonymous, 1971).

The pupal period did not vary much in different months. Sandhu (1972b) also observed that the pupal period was not extended in cooler months. Under laboratory conditions, Pradhan (1971) has, however, reported that the pupal period varied with varying temperatures.

Observations were also made regarding the larval behaviour for pupation in different seasons. The pupation took place usually in the leaf-folds and the basal portion of the leaves in March to June, whereas the larvae shifted

to the soil for pupation in September and December. This behaviour of larva to select site for pupation has not been reported earlier. It may be deduced that pupation occurs where optimum temperature and relative humidity are met with.

The longevity of adults was also variable in different seasons, it being more in December and less in June. The total life period of the fly also varied considerably during different seasons. It was the longest (33-41 days) in December and the shortest (23-29 days) in June. A total of 15 generations was found to complete its life cycle in one year. Moiz and Naqvi (1968) from Pakistan also reported 15-16 generations of sorghum shoot fly in one year.

5. Host non-preference

The non-preference for oviposition has been evaluated as a factor responsible for resistance in sorghum lines to shoot fly attack and reported less number of eggs on resistant varieties than on susceptible ones (Jain and Bhatnagar, 1962; Blum, 1969b; Jotwani et al., 1971 and Soto, 1974). The mechanism of resistance has been demonstrated to be non-preference for oviposition in shoot fly (Rao, 1972b).

In the present studies also the number of eggs laid was comparatively less in the resistant lines than those in the susceptible checks. Oviposition was more on

third and fourth leaves than on other leaves. Rajurkar and Thakare (1973) have stated that the flies usually preferred those plants for oviposition which could provide necessary food material for the development of maggot.

Blum (1972b) has reported that the seedlings of resistant genotypes possessed glossy, light green leaves, whereas the dull green colour with waxy bloom in seedlings were always infested. It is difficult at this stage to elucidate the factors responsible for the ovipositional non-preference in certain sorghum varieties, although plant characters like the colour and the glossiness of leaves exist yet it is not known whether these differences influence oviposition (Soto, 1974).

6. Antibiosis

The studies on the phenomenon of antibiosis in different varieties of sorghum to shoot fly showed that the promising lines exhibited antibiosis to some extent as against the susceptible checks. The observations revealed that the durations of egg and pupal periods were not affected by the varieties, whereas the larval period and the adult longevity were influenced considerably. In resistant lines, the larval period was markedly extended and the adult longevity was reduced as compared to the duration of these stages in susceptible ones. The longest larval duration (13-16 days) was observed in IS 5566 as compared to the lowest (8-9 days) in Swarna. Krishnananda (1969)

has observed the larval period to be prolonged by 6 days in IS 5566. The antibiosis was also observed in lines IS 5801 and IS 5604 (Young, 1972). Granados (1972) reported the egg and the pupal periods of sorghum shoot fly to be the same, but the larvae took one day more to complete the development and the adult longevity was reduced by 3.5 days when reared on a grass (Brachiaria reptans) than of those reared on sorghum.

The extension of larval period as reported by Blum (1969a) and the reduction of adult longevity may have a practical value. The former phenomenon may reduce the number of generations in a season and the latter ~~one~~ may be helpful in reducing the egg laying period of the fly.

The time required for the appearance of shoot fly damage symptoms in promising varieties of sorghum was observed to be different. The withering of central leaf occurred within 24-36 hours in resistant lines as against 6-12 hours in susceptible checks after the maggot penetration. Similarly 'dead heart' injury became conspicuous after a period of 2-3 days in resistant lines as against 1-2 days in the susceptible ones. Similar observations have been made by Blum (1969a), who reported that the infestation was delayed by two days in resistant varieties as compared to that in the susceptible ones. This delaying of injury may be important in exerting biotic pressure against the shoot fly (Starks, 1972).

The results of the study on the mechanism of antibiosis revealed that the resistant lines had a high density of silica bodies, both of dumb-bell and irregular shaped bodies, as compared to that in the susceptible ones. The distribution pattern of the silica bodies also varied in the resistant and susceptible varieties. In resistant lines, silica bodies were arranged in closely spaced bands of 3-5 chains, whereas in susceptible varieties the bands of 2-3 chains were placed quite apart. From these observations, it is clearly indicated that the density and the distribution of silica bodies may be the basis of antibiosis in certain sorghum varieties. Ponnaiya (1951b) and Blum (1968) have also reported that the presence of silica bodies in the resistant plants, was the cause of resistance. Djamin and Pathak (1967) considered high silica contents in the plant to interfere with feeding and boring of larva and could cause injury to mandibles of insect in rice plant. The same concept may hold good here as well and the cephalic of hooks of maggot perhaps are damaged while feeding in resistant varieties.

Mechanism of resistance needs exploitation. According to Horber (1972), insect resistant plants are an ideal preventives against insect damage. These involve minimum production costs and are non-polluters and are, therefore, attractive in this environmentally conscious age.

Conclusion : The studies on the biology of shoot fly have revealed that the egg laying and hatching and the emergence of larva and adult took place invariably during the early morning hours. It would, therefore, be highly pertinent to confine the suitable control measures to the early morning, from 0600 to 1000 hours. The studies on seasonal incidence of the fly indicated two peak periods, one in April and the other in September. It would, therefore, be worthwhile to adjust the sowing time accordingly to save the crop from the fly attack. Pupation occurred in plants during summer and in soil during winter and thus necessary methods can be explored to control the fly in different seasons. Resistant sorghum lines have exhibited some degree of antibiosis. Silica contents were higher in resistant seedlings which may be helpful in screening the plant material.

Chapter VI

SUMMARY

The present dissertation reports the experimental findings of the biology of sorghum shoot fly, Atherigona soccata Rondani (Diptera : Muscidae) with reference to the phenomenon of antibiosis. The results indicate that:

Eggs were opaque white, rod shaped and varied with age very minutely in size; older eggs were broader (0.32 mm) than the freshly laid eggs (0.29 mm). A majority of the eggs (52.6 to 70.0%) hatched in 36-48 hours and as many as 92 per cent eggs hatched in the morning before 0800 hours.

The newly emerged maggot measured slightly smaller (1.28 x 0.17 mm) than the egg (1.37 x 0.32 mm) before hatching. The full grown maggot measured 8.20x0.80 mm. The larva passed through three instars, which lasted for 36-48 hours, 2-3 days and 5-6 days respectively.

The prepupa was differentiated which measured 4.25 x 0.91 mm and it lasted for 6-8 hours. Pupa was obtect, dark brown and measured 3.60 x 1.23 mm. and lasted for 6-8 days. Adult emerged through a circular disc of pupa and showed slight body movement for 10-12 minutes before taking to flight. Adults survived for 6-7 days in capivity. The total life period was worked out to be 22-28 days.

Adults were attracted towards the brewer's yeast in the laboratory and fed on honey dew in the field. In mating, male played the active role and mating occurred in the morning hours which lasted for 2-5 minutes. Egg laying was started 1-2 days after mating. The female surveyed a few seedlings before depositing the egg. In the process of egg laying body was twisted 3-4 times and egg was laid by contracting the abdomen. Eggs were laid usually in the morning hours, on the underside of the fully exposed third or fourth leaf of the three or four leaf stage seedlings.

The maggot took 2-3 minutes to come out of the egg shell. Dew droplets enhanced the maggot movemant on the leaf surface and it entered into the plant within 30-50 minutes. On reaching the plant base, the maggot severed three fourth of the sheath and fed on the growing point. The first instar essentially fed on the fresh tissues while the other two instars fed on fresh to pale brownish semirotten tissues. Larvae died when offered decaying rotten tissues.

The third instar larva migrated from the mother shoot to its developing tiller and on entering through the whorl, caused 'dead heart' injury. In general, one larva per shoot was found though the seedling had two or more eggs. In a few cases, two or more maggots of the first instar, were also found in the leaf folds.

The external symptoms on the seedling, appeared 3-4 hours after the larval penetration and withering of central leaf occurred in 6-10 hours. The 'dead heart' was formed in 1-2 days and the plant was totally damaged in 4-5 days.

The sorghum shoot fly had two peak periods of its high incidence, the one during April and the second in September, when 62.9 to 73.6 per cent and 75.5 to 82.6 per cent 'dead hearts' were caused respectively.

The duration of life cycle of the fly varied in different months, being 21-25 days in April-October and 30-39 days in November-March. Pupation occurred in the plant (basal portion or leaf folds) during summer and in the soil during winter. The fly completed fifteen generations in a year,

In shoot fly resistance in sorghum, non-preference for oviposition was operative. IS 5622 was least preferred for oviposition. The other promising lines IS 5566, IS 5383, IS 2123 and IS 5604 also attracted less eggs than the susceptible checks.

Antibiosis phenomenon of resistance in promising lines was also operative to some extent. The larval period was extended to 13-16 days in IS 5566 as compared to 8-9 days in Swarna. Adult longevity was found to be 2-3 days in resistant and 6-7 days in susceptible varieties. The damage symptoms appeared late in resistant varieties.

Withering of central leaf occurred in 24-36 hours and 'dead hearts' were formed in 2-3 days after larval penetration as compared to that of 10-12 hours and 1-2 days respectively in susceptible varieties.

Higher silica contents per unit area in the younger leaf sheaths of resistant varieties were recorded. The silica bodies were distributed in close bands in resistant lines than in susceptible varieties.

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* Original not seen.

Appendix I : Meteorological data* for Ludhiana during 1971-1973

Month	Temperature °C			Relative humidity** (%)	Rainfall (mm)
	Maximum	Minimum	Mean		
1971					
March	27.8	10.5	19.1	62.9	1.6
April	35.2	18.1	26.7	47.8	1.1
May	36.9	21.6	29.3	44.0	46.6
June	36.6	26.5	31.5	60.0	115.6
July	33.8	25.0	29.4	74.1	199.8
August	33.3	24.3	28.8	76.5	266.1
September	33.5	20.7	27.1	65.7	20.1
October	32.6	15.3	23.9	55.0	-
November	26.4	9.8	18.1	61.0	20.6
December	22.1	5.3	13.7	64.5	-
1972					
January	19.9	4.6	12.3	66.5	8.5
February	18.8	4.5	11.7	63.5	41.2
March	27.2	10.8	19.0	64.0	16.8
April	32.5	14.5	23.5	48.5	16.5
May	40.0	20.7	30.3	27.0	-
June	40.2	24.9	32.6	41.0	45.1
July	35.6	25.0	30.3	65.0	262.2
August	33.0	23.8	28.4	76.0	102.7
September	34.0	19.4	26.7	65.0	57.6
October	32.2	13.4	22.8	57.0	-
November	26.7	9.5	18.1	63.0	12.0
December	19.6	6.2	12.9	74.0	19.0
1973					
January	18.0	4.4	11.2	75.5	43.3
February	22.6	7.1	14.9	71.5	20.3
March	26.0	9.2	17.6	62.0	8.2
April	37.0	15.5	26.3	41.0	1.2
May	39.3	21.1	30.2	42.0	53.4
June	37.5	25.2	31.3	56.0	36.8
July	34.9	24.9	29.9	70.0	162.4
August	33.0	24.2	28.6	77.5	283.2
September	34.2	22.5	28.3	70.5	25.4
October	31.2	14.3	22.7	62.5	4.2
November	26.4	7.6	17.1	67.0	-
December	16.1	3.7	9.9	81.5	43.3

*Observations recorded at 0727 and 1427 hours

**Average of morning and evening records

Appendix II : Mean room temperatures during 1971-1973

Month	Temperature °C		
	Maximum	Minimum	Average
1971			
August	37.12	29.72	33.42
September	36.50	31.60	34.05
October	30.41	21.24	25.03
November	26.33	12.92	20.13
December	24.72	10.56	17.64
1972			
January	22.22	8.27	15.25
February	29.03	5.31	13.47
March	29.03	12.02	20.53
April	37.00	18.00	27.50
May	42.84	32.20	37.53
June	42.76	33.11	37.83
July	39.14	32.19	35.78
August	38.74	29.12	34.18
September	39.22	29.94	34.58
October	31.14	23.18	27.16
November	25.78	12.46	19.62
December	23.43	10.23	16.83
1973			
January	22.72	21.98	22.35
February	20.90	19.74	20.37
March	27.78	26.81	20.37
April	33.29	32.21	32.75
May	39.89	38.33	39.61
June	42.38	39.43	40.91
July	40.03	38.00	39.09
August	37.83	36.52	37.18
September	37.86	30.77	34.31
October	30.77	22.21	26.49
November	26.05	13.69	19.87
December	24.08	10.40	17.24

Appendix III : Number of eggs laid and 'dead hearts' caused (up to four weeks after germination) by shoot fly, Atherigona soccata on sorghum CSH-1 sown at weekly interval

(Ludhiana, 1971-1973)

Dates of Sowing	Dates of Germination	Total plants	Number of eggs laid on 25 plants* on weeks after germination I	II	III	IV	Total	Average eggs per plant	'Dead hearts' formed on weeks after germination I	II	III	IV	Total	Percentage of 'dead hearts'
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971														
21/3	28/3	148							12	17	19	13	61	41.2
31/3	7/4	141							16	33	23	16	88	47.6
10/4	16/4	152							26	38	25	14	103	67.7
21/4	26/4	138							24	43	42	11	120	86.9
1/5	7/5	115							16	36	5	7	64	55.6
11/5	18/5**	84							1	13	5	0	19	22.6
21/5	27/5	103							7	15	11	2	35	33.9
1/6	6/6	118							1	7	3	0	11	9.3
10/6	16/6	131							2	8	5	0	15	11.4
21/7	25/7	130	4		7		11	0.22	6	14	7	2	29	22.3
4/8	9/8	147	18		26		44	0.88	7	12	13	7	39	26.5
11/8	16/8	130	11		17		28	0.56	11	21	10	4	46	35.3
18/8	23/8	162	16		20		36	0.72	14	28	15	9	66	40.6
25/8	31/8	168	25		36		61	1.22	12	24	23	21	80	47.6
1/9	6/9	177	37		113		150	3.00	28	45	40	28	141	79.6
8/9	14/9	190	69		72		141	2.82	37	34	31	22	144	75.7
15/9	21/9	192	71		55		126	2.52	43	69	33	23	178	92.7
22/9	28/9	180	64		31		95	1.90	51	60	25	12	148	82.2
29/9	5/10	184	48		18		66	1.32	52	53	36	8	149	80.9

Contd...

Appendix III contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6/10	13/10	148	37		12		49	0.98	43	32	18	3	96	64.8
13/10	20/10	142	21		6		27	0.54	37	28	13	2	80	56.3
10/11	21/11	85	6	18	8	4	36	0.36	2	11	2	0	15	17.6
17/11	28/11	35	2	5	4	1	12	0.12	3	6	0	0	9	25.7
24/11	5/12	42	2	5	1	0	8	0.08	1	7	1	0	9	21.4
1/12	18/12	18	0	2	0	0	2	0.02	0	2	0	0	2	11.1
10/12		No germination												
20/12		No germination												
1972														
10/1		No germination												
20/1		No germination												
30/1	14/2	12	0	0	0	0	0	0.00	0	0	0	00	00	0.0
9/2	20/2	18	8	16	4	1	29	0.29	0	1	2	0	3	16.6
16/2	25/2	27	7	12	14	12	45	0.45	0	4	1	1	6	22.2
23/2	3/3**	22	16	18	13	13	60	0.60	1	3	1	3	8	36.3
1/3	8/3	150	18	28	52	32	110	1.10	8	27	13	2	50	33.3
8/3	15/3	103	27	32	36	18	113	1.13	14	23	13	3	53	51.4
15/3	21/3	134	42	48	37	23	115	1.15	20	23	28	27	98	73.1
29/3	4/4	162	63	76	37	27	203	2.03	42	48	16	20	126	77.7
5/4	10/4	153	78	65	48	23	214	2.14	32	59	19	12	102	66.6
12/4	17/4	160	108	63	47	41	259	2.59	15	19	27	17	98	61.2
19/4	24/4	192	67	66	41	23	197	1.97	18	51	29	18	116	60.4
26/4	30/4	178	26	47	27	31	131	1.31	32	29	21	8	90	50.5
3/5	7/5	205	31	31	18	6	86	0.86	28	41	21	4	94	45.8
10/5	19/5**	97	12	18	4	1	35	0.35	18	19	10	6	53	54.6
17/5	21/5	208	17	22	16	12	67	0.67	8	31	11	6	56	26.9
24/5	28/5	167	14	17	8	5	44	0.44	10	22	6	4	42	25.1

Contd...

Appendix III contd..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
31/5	3/6	148	4	11	2	1	18	0.18	6	6	4	1	17	11.4
8/6	14/6**	69	2	1	1	6	10	0.10	2	13	8	3	26	37.6
14/6	17/6	143	4	0	2	1	7	0.07	4	12	17	8	41	28.6
22/6	26/6	129	3	6	10	11	30	0.30	3	11	3	2	19	14.7
29/6	3/7	133	2	5	14	0	21	0.21	7	13	6	3	29	21.8
5/7	9/7	98	17	11	4	3	35	0.35	6	11	3	2	22	22.4
12/7	16/7	127	11	4	6	2	23	0.23	11	13	9	4	37	29.1
19/7	23/7	141	3	7	9	3	22	0.22	13	18	6	1	38	26.9
26/7	30/7	148	12	2	3	3	20	0.20	8	7	7	1	23	15.5
3/8	7/8	129	6	7	4	2	19	0.19	6	11	7	5	29	22.4
16/8	20/8	146	12	42	33	33	120	1.20	13	17	6	5	41	28.0
23/8	26/8	129	18	40	22	12	92	0.92	19	33	21	10	83	64.3
31/8	4/9	163	42	58	67	26	193	1.93	18	46	26	15	105	64.4
7/9	11/9	172	58	84	63	37	242	2.42	22	60	21	10	113	65.6
14/9	18/9	165	54	76	62	32	204	2.04	23	65	38	16	142	86.0
20/9	24/9	192	52	58	36	16	162	1.62	29	59	57	18	163	84.8
4/10	8/10	154	37	45	12	7	101	1.01	18	46	31	7	102	66.2
11/10	16/10	125	27	32	21	8	88	0.88	19	30	27	11	87	69.6
18/10	24/10	128	22	22	12	2	58	0.58	13	27	9	2	51	39.8
25/10	1/11	114	12	8	7	3	30	0.30	6	13	14	4	37	32.4
1/11	8/11	103	7	9	3	1	20	0.20	3	11	4	0	18	17.5
8/11	17/11	47	12	10	1	2	25	0.25	1	4	2	0	7	14.8
15/11	25/11**	12	0	0	1	0	1	0.01	0	0	0	0	0	0.0
22/11	12/12	6	0	1	1	0	2	0.02	0	0	0	0	0	0.0
10/12@		61	0	3	2	0	5	0.05	4	4	2	0	10	16.3
20/12@		66	2	3	1	0	6	0.06	3	4	1	1	9	13.6
30/12@		50	0	2	2	0	4	0.04	1	3	0	1	5	10.0

Contd...

Appendix III contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1973														
10/1@		56	0	0	2	1	3	0.03	0	2	1	1	4	7.1
20/1@		53	0	1	2	1	4	0.04	1	2	0	0	3	5.7
7/2	14/2	36	0	0	2	0	2	0.02	0	2	1	0	3	8.3
21/2	28/2	32	0	0	1	1	2	0.02	1	1	2	0	4	12.5
28/2	5/3	61	0	4	2	4	10	0.10	3	2	4	7	16	26.2
7/3	14/3	48	2	11	11	13	37	0.37	1	4	11	11	27	56.3
14/3	20/3	85	14	26	36	12	88	0.88	8	11	17	2	38	44.7
21/3	26/3	103	27	28	45	19	119	1.19	16	41	22	8	87	84.4
29/3	4/4	103	18	36	20	13	87	0.87	16	24	33	13	86	83.5
4/4	9/4	154	27	48	55	55	185	1.85	24	41	36	16	117	75.9
11/4	17/4	168	51	76	56	38	221	2.21	26	46	31	23	126	75.0
18/4	23/4	168	47	76	31	16	170	1.70	27	52	21	8	108	64.2
2/5	7/5	167	41	24	16	10	91	0.91	26	46	32	13	117	70.1
9/5	13/5	168	21	24	16	5	66	0.66	11	23	14	4	52	30.9
16/5	21/5	171	15	18	6	4	43	0.43	17	28	13	9	67	39.2
23/5	28/5	163	6	4	3	1	14	0.14	11	21	3	3	38	23.3
30/5	4/6	178	12	8	4	0	24	0.24	6	7	3	3	19	10.7
8/6	18/6**	58	4	6	1	0	11	0.11	4	7	2	3	16	27.5
16/6	21/6	169	5	10	3	6	24	0.24	3	9	4	1	17	10.1
20/6	30/6**	43	0	2	2	0	4	0.04	3	6	2	1	12	27.9
29/6	3/7	137	6	12	1	3	22	0.22	5	9	5	2	21	15.3
6/7	10/7	117	4	4	15	6	29	0.29	2	7	4	3	16	13.7
13/7	17/7	144	12	8	7	3	30	0.30	8	17	6	3	34	23.6
20/7	24/7	98	6	13	7	9	35	0.35	3	6	4	3	16	16.3
27/7	31/7	133	21	16	5	4	46	0.46	3	13	7	2	29	21.8
3/8	7/8	148	21	18	4	1	44	0.44	10	18	6	3	37	25.0

Contd...

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Appendix III contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
10/8	14/8	162	26	31	2	1	60	0.60	13	14	8	11	46	28.4
17/8	21/8	172	30	14	7	3	54	0.54	14	26	18	11	69	40.1
21/8	27/8	129	19	27	8	12	66	0.66	17	26	33	13	89	68.9
31/8	3/9	144	53	59	46	30	188	1.88	27	39	31	17	114	79.1
7/9	11/9	167	48	72	54	36	210	2.10	32	53	21	17	123	73.6
14/9	19/9	156	46	56	52	27	183	1.83	36	41	27	27	131	83.9
21/9	27/9	198	46	69	41	39	195	1.95	36	48	33	31	148	74.7
28/9	4/10	154	52	67	26	9	154	1.54	21	56	10	11	98	63.6
5/10	12/10**	38	41	69	32	8	150	1.50	0	5	2	1	8	21.0
12/10	19/10**	11	37	68	19	6	130	1.30	2	3	0	2	7	63.6
19/10	27/10	102	31	48	21	8	108	1.08	16	21	15	10	62	60.7
26/10	4/11	109	31	19	13	7	70	0.70	26	11	18	3	58	53.2
2/11	13/11	82	23	17	8	6	54	0.54	8	14	1	4	27	32.9
9/11	21/11	48	13	11	8	1	33	0.33	8	11	4	0	23	47.9
16/11	30/11	18	5	12	3	1	21	0.21	1	0	1	0	2	11.1
23/11	5/12	12	0	1	1	0	2	0.02	0	2	0	0	2	16.6
1/12@@		86	2	3	4	0	9	0.09	4	7	4	1	16	18.6
10/12@@		80	0	1	2	0	3	0.03	0	1	6	0	7	9.0
20/12@@		22	0	2	0	0	2	0.02	0	0	0	0	0	0.0

*Where seedlings were less than 25, count was taken on all and values transformed for 25 seedlings.

**Due to non-availability of timely irrigation, there was poor germination.

@ No germination in the field, observations were recorded on seedlings raised in flats.

@@ Owing to poor germination, observations were recorded on tillers.

Note Certain sowings were missing due to certain un-avoidable circumstances.