THE BIOLOGY OF *APION SOLEATUM* WAGNER (COLEOPTERA: APIONIDAE) WITH RESPECT TO COTTON IN SOUTH AFRICA

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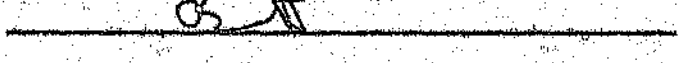
This dissertation reports the results of an investigation of the distribution morphology, life cycle, effect on cotton growth, quality and yield, as well as the feeding preferences of A. soleatum, the cotton stem weevil, in South Africa. A. soleatum was found to occur only in the Eastern Transvaal and Northern Natal cotton producing regions. A detailed study of this weevil's morphology confirmed that it was rightfully included in the family Apionidae, but that its placement in the genus Apion Herbst was inconsistent with the characteristics of this genus. A. soleatum oviposits in cotton, its major host; larval and pupal development taking place in the stems. Adults feed on the leaves, and are found predominantly near the apex of plants. The larval stage, of which there are three instars, was shown to be responsible for losses in cotton yield and diminished growth of cotton plants in general. Entedon apionidis, a parasitoid wasp was found associated with A. soleatum larvae and pupae.

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University



2nd day of December, 1991.

Judging simply from their structure, habits, and economy,
there are reasons why
Beetles ought to excel every other class of organised beings...

Andrew Murray

Unbidden guests
are often welcomest when they are gone

William Shakespeare

Then come those humbler men of heart
With no completed scheme,
Content to play a modest part,
To test, observe, and dream,...

William Dampier-Whetham

.... in the waning year
Potters a coleopterist, poking
Through yellow leaves.

W. H. Auden

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PREFACE

During the early half of the 1980's, Apion soleatum caused alarm within both the private and public sectors of agriculture in South Africa. The term 'a new pest' was frequently applied, even though work on this insect, with the exception of its description, had never seen the light of day. This study was undertaken to gain information on the life history of this weevil and to assess its potential impact on the South African cotton industry.

During the course of this study, which ran parallel with two others that comprised my duties at the Tobacco and Cotton Research Institute in Rustenburg, I was invaluably assisted in respect of consultative discussions and logistical help, by many people and organisations. These include Messrs Bill Goodwin, Alf Harding and John Snell of Hoechst, South Africa, who generously arranged the use of Hoechst's facilities at Malelane. Messrs Klasie Reynolds, Sample Muy and especially Piet Dreyer of Clark Cotton, Pongola, arranged for, and accompanied me on, numerous trips to cotton farms during surveys in the Northern Natal region. The transport used was at Clark Cotton's expense and deserves special mention. Mr André Groenewald of Mjindi Estates in the Makatini is thanked for allowing me to collect specimens on the estate. Mr Paul van Dyk, of the Tobacco and Cotton Research Institute assisted with the trials in Malelane, particularly during May and June of 1990 when I was called up to do a period of military service, and is gratefully acknowledged. Mr Rolf Oberprieler (National Collection of Insects, Pretoria), Dr Miguel Alonzo Zarazaga (Malaga, Spain) and Ms Luisa Alcantara Santos are thanked for discussions and information concerning the Apionidae. Miguel Alonzo Zarazaga confirmed the conspecificity of the South

African weevil with that of the type specimens in the British Museum of Natural History. The staff of the Tobacco and Cotton Research Institute were always available for discussion and Dr M. Dippenaar, Dr H. van Heerden, Mr R. van Wyk, Dr M. Greeff, Mr E. Eulitz and Mr G. de Villiers gave freely of their time and expertise. Ms Hannelie Swanepoel kept the "non-Apion" projects going during my absences. This was especially appreciated. Mrs Elize Eulitz and Ms Annette Swanepoel taught me, in the space of a few days, how to use several computer software packages, which made the production of this dissertation much easier. Special appreciation is expressed to Karen, Merle, Jan, Cornel and the other inhabitants of the singles quarters. They met with patience and good natured encouragement, my impatience and irritability. Linda Serfontein came to the rescue with last moment field cage repairs. I recall many pleasant evenings spent in the company of Alf and Brenda at Malelane. To all these persons, and those who are not mentioned here, but who in their own way lent encouragement, a real appreciation is expressed.

Especial thanks are expressed to Mr Hans Mahneke, who assisted me with the translations of the German papers written by Wagner, and also to Prof. Robin Crewe, my supervisor, for the time consuming and tedious task of directing this study.

My most heartfelt and sincere gratitude is directed to Ms Annette Nel, who spent many hours encouraging me, many days at my side next to the computer, many months obtaining references for me and reading the manuscript, and years of friendship and understanding.

The ingrained appreciation that I have of nature and the outdoors was developed in me by my parents, who were always fascinated by the vagaries of wild

creatures, and stimulated my curiosity in them during my formative years. For their continual insistence that one must not and cannot ever stop learning, I will be eternally grateful. The sacrifices they made to give me a balanced education, and the opportunity to study, are deeply appreciated.

A single scientific note was published in volume 53 of the Journal of the entomological Society of southern Africa, and formed the basis of the section (5.3.3) on natural enemies of A. soleatum. In addition, two articles concerning the morphology of A. soleatum have been submitted to the above journal for publication. The study was hampered by the fact that permission to bring live A. soleatum to Rustenburg was not forthcoming, even though tentative permission had been granted at the outset of the project. The risk of A. soleatum escaping into local cotton, where it had not yet been recorded and without the presence of the parasitoid, was the main reason why A. soleatum could not be studied in Rustenburg.

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CHAPTER 1. INTRODUCTION

1.1 Cotton production and associated insect pests in South Africa.

South African cotton is produced under both irrigated and dryland practices. The number of hectares devoted to cotton production has increased dramatically over the latter half of the 1980's, from 107 454 ha in the 1984/85 season to 208 360 ha in the 1988/89 season (Cotton Board Annual Report 89/90). Over the same period production increased from 179 134 bales of lint cotton to 388 341 bales, an increase of 216 percent. The average price for lint was 355 cents per kilogram in 1990. At 200 kg lint cotton per bale, it represents a market worth some 275 million rand annually and does not take into account the value associated with seed production or other cotton related markets. At present South African consumption exceeds production, and ensures that the cotton industry will grow in the future.

Cultivated cotton belongs to the genus Gossypium L. in the family Malvaceae, and commercial varieties belong to four species, namely G. herbaceum, G. arboreum, G. barbadense (Sea Island cotton) and G. hirsutum (Upland cotton) (Pearson 1958). The cultivars most widely utilised for commercial production in South Africa belong to G. hirsutum and include Acala 1517/70, Deltapine Acala 90, as well as some locally bred cotton types such as Tetra, Gamma and OR3 (Greeff 1986). Most cultivated cotton types take the form of a perennial shrub with a vigorous tap root system and a single ascending main stem which bears at each node a leaf and usually one branch. Vegetative branches or monopodia tend to be produced lower down on the plant, while reproductive or sympodial

branches are produced higher up on the monopodia. Sympodia are generally short and terminate in a flower bud. The cotton flower is a creamy-yellow colour and remains open for only one day. Pollination usually occurs in the early afternoon and by late afternoon the corolla begins to change colour, becoming first a faint pink and later a deeper red-mauve. At the same time the bracts (calyx) close around the ovary. At this stage the bud is termed a square. As the square develops, the fruit increases in size and protrudes beyond the bracts. The fruit or boll is a 3-5 locular, dehiscent capsule, each locule containing some nine seeds. It is these seeds which, in addition to a short fuzz used in the explosives industry, produce the lint fibres (Van Heerden 1977) (Fig. 1).

Although cotton is a perennial shrub which can be ratooned (ie left to stand over until the following season, thereby avoiding planting again), most producers cultivate cotton on an annual basis with planting commencing some time in October/November and harvesting occurring in April/May. A good discussion of the advantages and disadvantages of ratooning cotton is given by Niles and Greeff (1989). The practise is generally not encouraged since it provides a winter habitat for many pest species and ensures high early-season pest populations. During the production season, a cotton crop is vulnerable to attack from a wide range of insects. In South Africa key pests are Helicthis armigera (Hübner) (American bollworm; Noctuidae) and Tetranychus cinnabarinus (Boisduval) (Red spider mite; Tetranychidae). Other pests include Diparopsis castanea Hampson (Red bollworm; Noctuidae), Earias insulana (Boisduval) and E. biplaga Walker (Spiny bollworms; Noctuidae), various other Tetranychus species, Aphis gossypii Glover (Cotton aphid; Aphididae), Jacobiella species (Cotton leafhopper; Cicadellidae) and various cotton stainers such as Oxycarenus hyalipennis (Costa) (Lygaeidae) and Dysdercus species (Pyrrhocoridae). In addition, various Coleoptera also attack cotton. Adult Systrus rufifrons Baly

(Chrysomelidae) can cause considerable defoliation while the larvae attack the roots and young seedlings (Broodryk 1964). The larvae of Protostrophus species (Curculionidae) feed on germinating seeds, causing heavy localised stand reductions early in the season. The whitefly, Bemisia tabaci (Gennadius) (Aleyrodidae) is also known to vector viral diseases. It is thus obvious that the pest complex associated with cotton is wide and control procedures are complicated. For example, with respect to the key pests, the use of pyrethroid pesticides against the bollworm complex reduces the spider mite natural enemy populations with a concomitant increase in spider mite densities. For these reasons, the control of any new pest of cotton must be tested to determine its effects on existing pests.

Apion soleatum Wagner, the cotton stem weevil, was identified as a potential pest of cotton in South Africa during the 1984/85 season. During that period it was found in the cotton growing areas of Kangwane (Broodryk & Mansfield 1985), and since then it has spread to areas of the eastern Transvaal (Holtzhausen, pers. comm.), northern Natal (Eulitz 1987, unpub. report; Bennett 1988, unpub. report) and Swaziland. Since August 1988 it has been found to occur in the Pongola, Hectorspruit (Bennett, pers. obs.), and Makatini (Swift, pers. comm.) areas. In a survey undertaken by myself in the Pongola area, 160 cotton plants were investigated and 47 adults, 4 pupae and 26 larvae were recovered (Bennett 1988, unpub. report). On a stand of ratoon cotton (1,3 ha., 2nd season) in the Malelane area, over 300 adults and more than 200 pupae and larvae were collected over a period of two months in 1988. This clearly demonstrates that without adequate control, A. soleatum has the potential to achieve high densities. It is these high levels which have lead to cotton yield reductions of up to sixty percent on pre-harvest forecasts, according to Mr John Eckstein (Gin manager, Hectorspruit, 1988, pers. comm.).

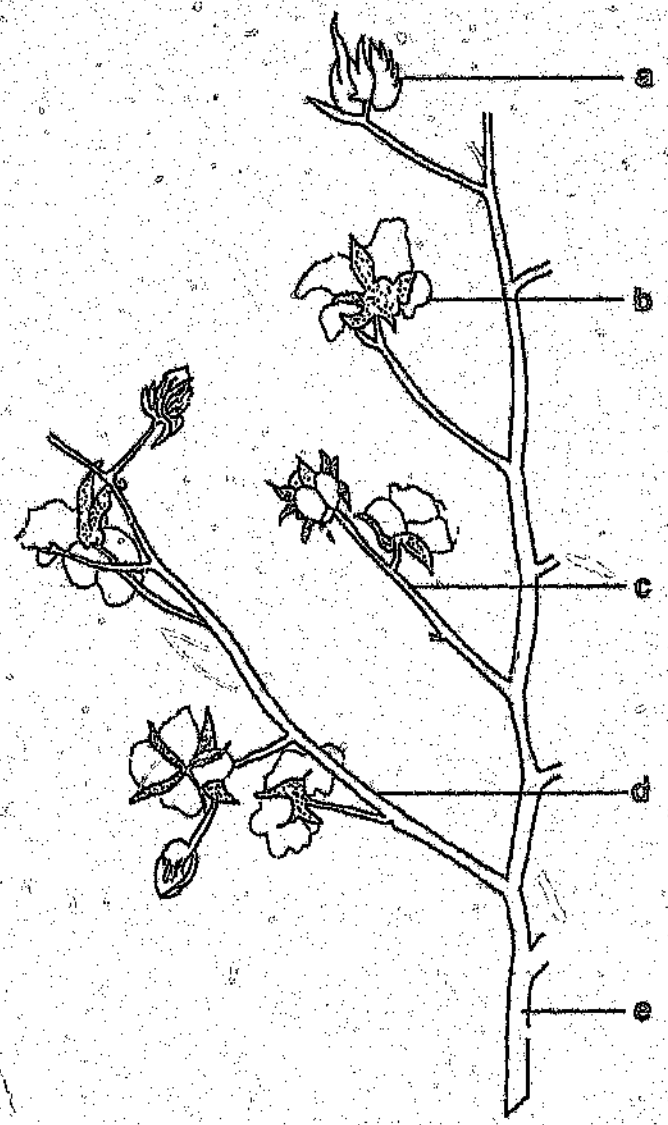


Fig. 1 The morphology of the cotton plant
a square, b burst boll, c sympodium
d monopodium, e main stem

1.2 Statement and analysis of the *Apion soleatum* problem

The relatively recent exploitation by *A. soleatum* of local cotton is curious (Bennett and Nel 1990), and the visibly high numbers of this insect, which during the mid 1980's was unknown in South African cotton, caused alarm amongst both producers and buyers. As the seasons progressed and *A. soleatum* remained in cotton, producers became anxious to know more about this weevil. Preliminary perusal of the literature that existed indicated that yield losses had been attributed to *A. soleatum* in eastern and central Africa during the post-World War I years (Pearson 1958). No further information with respect to *A. soleatum*'s potential impact on cotton existed and consequently several pertinent questions, which formed the basis of this study, presented themselves.

i. To what extent is *A. soleatum* distributed over the cotton producing areas of South Africa, and consequently to what extent does it threaten the cotton industry?

ii. How does one identify *A. soleatum* and can one distinguish between the sexes?

iii. What sort of life history does *A. soleatum* exhibit? Do any alternate hosts exist? Do any natural enemies exist?

iv. Does *A. soleatum* deserve pest status, and if so, how can one recognise this weevils' damage to cotton? What are the effects of *A. soleatum* on cotton yield and quality?

v. How can one best control this insect?

1.3 Scope and objectives of this study

To find satisfactory answers to all the questions stated earlier is far beyond the scope of an MSc. study. Certain objectives were therefore identified for study, bearing in mind the importance of determining whether the threat posed by this insect to the cotton industry, justified further, extensive research. Another criterion that was used to identify study objectives was the fact that an adequate knowledge of any potential pest's morphology and biology is necessary before an investigation of its control can begin. Consequently five major objectives were identified for study. The first was to determine the distribution of A. soleatum in the cotton producing areas of South Africa. This was deemed necessary so that an assessment could be made of the extent to which the cotton industry could be threatened. The second objective involved the detailed description of A. soleatum, since this insect is not a true member of the genus Apion Herbst, even though it was originally described as such. Thirdly an investigation of the with-in plant distribution and feeding preferences of A. soleatum was chosen, since such data would assist in pin pointing target regions of the plant for pesticide application. In addition such data would indicate probable reasons for yield and quality reductions in cotton attacked by A. soleatum, should they occur. The fourth objective was to obtain data concerning the life-cycle of the insect, especially with regard to the number of generations per season and the number of larval instars. The final objective was to determine whether A. soleatum deserved pest status and at what densities it affected cotton yields and quality. The study as a whole necessitated a detailed review of relevant literature. Since virtually no publications with respect to applied and biological topics exist, this aspect of the study involved a review of taxonomic information.

CHAPTER 2. LITERATURE REVIEW

2.1 The history of the higher classification of Apion Herbst

2.1.1 Pre 1912. (Wagner and earlier workers)

Schöenherr (1823), using a non-Linnaean system of classification, established Divisio 5 Apionides. According to Oberprieler (1989, pers. comm.) he can thus be regarded as the author of the Apionidae, the Apioninae and the Apionini. LeConte (1874) referred to the group as a family, however LeConte and Horn (1883) redefined it as a subfamily. According to Wagner (1912), LeConte and Horn (1883) gave no morphological basis for their classification. Apioninae sensu LeConte and Horn (1883), did not include the genera Myrmacicelus Chevrolat or Cylas Latreille, which were placed in a separate subfamily, the Cyladinae. Faust (1889) used the criterion of whether the femur attains the coxa or not, to distinguish the subfamily Apioninae from other curculionid subfamilies. Wagner (1909) considered this criterion as being useful only in the separation of tribes and used the following criteria to distinguish his subfamily: Abdomen with five visible sternites; sterna 1 and 2 broad, each at least as broad as sterna 3 and 4 together; sternum 5 flat and at least as broad as sterna 1 and 2; coxae of metasternum separate; elytra completely covering the abdomen; antennae straight.

The subfamily Apioninae sensu Wagner (1909) comprised two tribes, the Eurhynchini and the Apionini, this subdivision being based on the criterion of whether or not the femur attains the coxa. In doing so, according to

Phelps (1955), he disrupted the classifications of earlier workers such as Schöenherr, and several genera, then classified in different categories, were included in his subfamily.

The tribe Eurhynchini sensu Wagner (1909) included three genera, namely Eurhynchus Schöenherr, Chalcocybebus Snellen and Cylas Latreille. In 1912 he included the genus Ctenaphides Pascoe. The following groups of genera, of early workers, contained synonyms of members of his tribe Eurhynhini: Apionides of Schöenherr, Cylades of Schöenherr, the Eurhynchides of Lacordaire and the Cylades of Lacordaire (Wagner 1912).

The tribe Apionini sensu Wagner comprised species in which the coxa and the femur were separated by a well developed trochanter. In his earlier work (Wagner 1909) ten genera were included in this tribe, namely Megatrachelus Faust, Rhadinocyba Faust, Pterapion Faust, Mecolenus Schöenherr, Cybebus Schöenherr, Myrmacicelus Chevrolat, Podapion Riley, Tanaos Schöenherr, Apion Herbst and Heterapion Sharp. In his later work Wagner (1912) excluded Heterapion but included the two new genera Lispotherium Faust and Apiomorphus Wagner. As groups of genera of earlier workers, which contained synonyms of members of this tribe, Wagner (1912) listed the following: Apionides of Schöenherr, the Cybebidos of Lacordaire, the Apidae of Bedel and the Apioninae of Faust.

Only seven genera were included in Faust's (1889) Apioninae. All of these with the exception of Apiemonus ppeared in Wagner's (1912) list. The genus Tanaos was placed in the Eurhynchides by Faust (1889) as he claimed that the femur and the coxa were not separate. Wagner (1912) disputed this

observation, stating that the much reduced trochanter in Tanaos still completely separated the femur and the coxa.

Of further interest was the suggestion by Wagner (1912) that further work in the Apioninae may result in the fusion of the tribes that he erected. He claimed that the form of the trochanter in Tanaos may be intermediate between the typical forms of the two tribes. Wagner (1912) investigated the number of antennal segments and the degree of atrophy of the suture between the first and second abdominal sternites, with a view to changing the tribal criterion. In the first case he found that the distal antennal segments become fused (indicated by a partial suture) and in the second, a wide range of variability in the appearance of the suture existed. He concluded by retaining his two tribes, despite the difficulties created by Tanaos (Fig. 2a).

2.1.2 Post 1912 (Crowson, Kissinger, Britton, Lawrence & Newton, Oberprieler & Louw).

Crowson (1954) treated the 'apionids' as a family. In this paper he stated that the Apionidae could be thought of as intermediate between the Attelabidae and the Curculionidae. Crowson (1954, 1960) was unclear as to why the group should be raised to family status. In the Apionidae he included the subfamilies Eurhynchinae, Apioninae, Ithycerinae and Nanophyinae. He considered the attelabid features of Apionidae to be primitive. These were the non-geniculate antennae, the absence of a distinct proventriculus and the larval frontal suture extending completely to the mandibular articulatory membrane. He placed Eurhynchus closest to the Attelabidae and [illegible] closest to the Curculionidae (Fig. 2b).

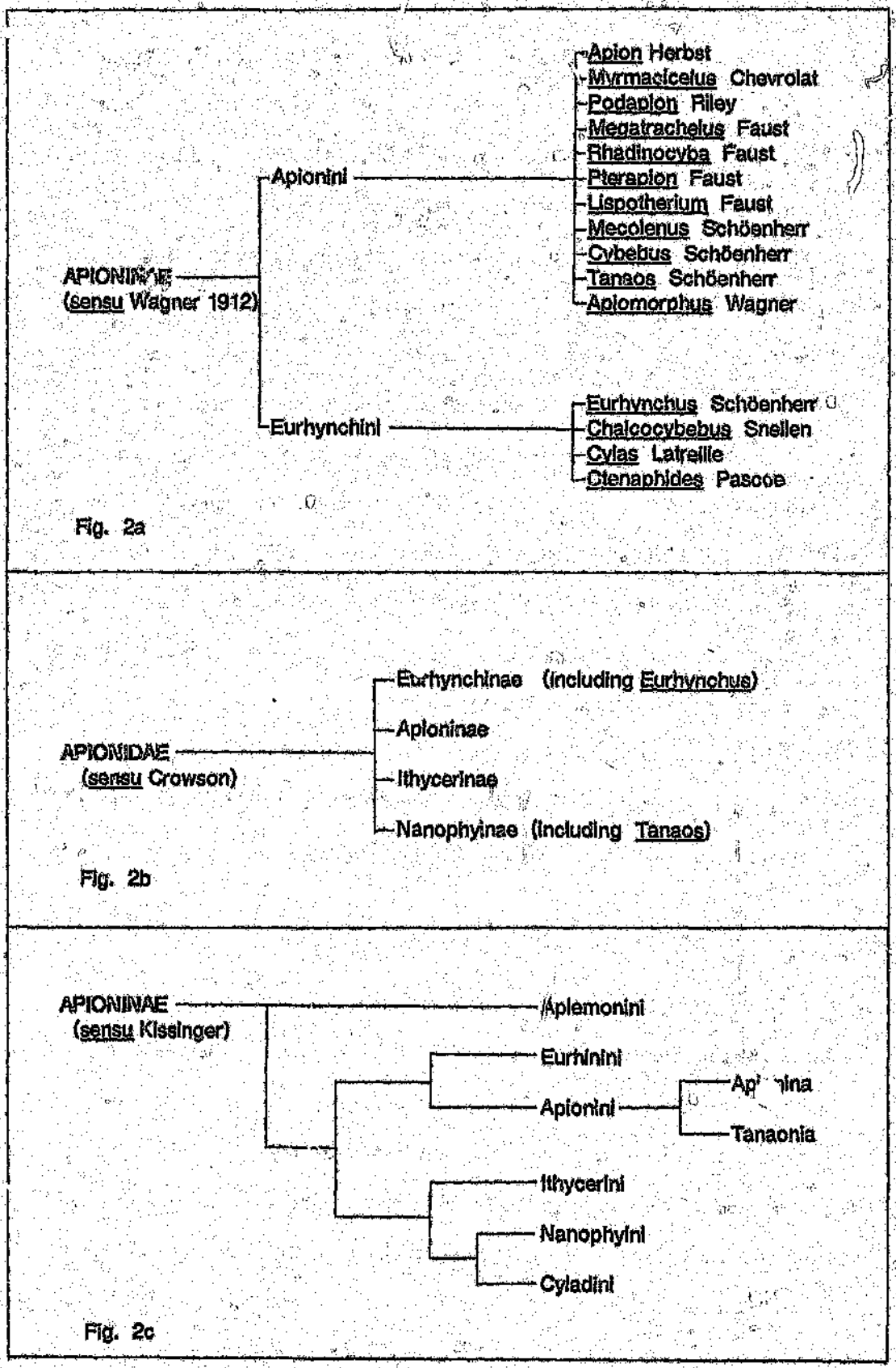


Figure 2. The classification of Apion Herbst according to different authors

Kissinger (1968), on the other hand, preferred the traditional status of subfamily for the group, arguing that the available evidence did not overwhelmingly indicate that the group should be of either family or subfamily status. Thus in his review of the world genera of apionids (Kissinger 1968), he red[illegible]e group as a subfamily of the Curculionidae and included in it the genera Ithycerus Schöenherr and Nanophyes Schöenherr. Junk's Coleopterum Catalogus had previously treated these as separate subfamilies within the Curculionidae. This move was also in keeping with Crowson (1954). Kissinger (1968) noted that the Apioninae presented formidable taxonomic problems because of the large number of forms involved. The world fauna comprised some 1500 species of minute proportions (1.5 - 3.0 mm). The structure and morphology within the group was remarkably uniform and thus provided few 'good' taxonomic characters. A further problem was the fact that there were only three levels of taxa between family and genus, namely subfamily, tribe and subtribe. In this respect it was perhaps desirable to raise the group to a family, as Crowson (1954) did. Kissinger (1968) suggested the use of a taxon called 'supertribe' with suffix '-oinea', but did not make use of it in 1968.

Kissinger's (1968) Apioninae comprised three groups of genera. The first, in which the mesocoxae were not separated by the meso- and metasterna, were represented by the tribe Aplemonini. This feature, according to him, is not seen elsewhere in the Curculionidae. The next subdivision was based on the nature of the tubular flagellum in the internal sac. Those without a flagellum, or with a very reduced flagellum comprised two tribes, namely the Eurhinini and the Apionini. The division between the two tribes was based on the nature of the antennal club, the apical tibial articulation and the suture between sterna 1 and 2. The Apionini was further divided into two

subtribes, the Apionina (nine striate elytra, articular rim of coxae even) and the Tanaonina (10 striate elytra, articular rim of coxae with tooth-like processes). The Apioninae possessing a well developed flagellum comprised the third group. Three tribes were recognised, namely the Ithycerini, the Cyladini and the Nanophyini (Fig. 2). The Cyladini (sensu Kissinger), were considered an advanced group, whereas they were included in Crowson's (1954) more primitive Eurhynchinae.

Subsequent to Kissinger (1968), various authors published general classifications (eg. Britton 1970, Lawrence & Newton 1982, Oberprieler & Louw 1985) in which the group was recognised as a family. It appears though recent workers feel that the group should be recognised as a family, although no reasons are given for this, and there are still many differences in opinion concerning the hierarchical status of the group.

Oberprieler & Louw (1985) in a treatise on southern African Curculionoidea follow Crowson's (1954) classification. In southern Africa only three of the subfamilies are represented (Oberprieler & Louw 1985). Two of the subfamilies are abundant (Apioninae and Nanophyinae) while the Cyladinae is represented by only a few species, one of which, namely Cylas formicarius (Fahraeus) (the sweet potato weevil), is of some economic importance. Oberprieler & Louw (1985) also pointed out that the systematic position of the Cyladinae would probably best be reflected by raising it to a family of the Curculionoidea. Again no reasons were given for this observation.

2.2 The genus Apion Herbst

The genus Apion was erected by Herbst (1797). The history of the genus from its establishment until 1912 was detailed by Wagner (1912). A considerable amount of work was accomplished by early workers and the increasing number of species described under the genus bears testimony to this. According to Wagner (1912), Gemminger and Harold listed 377 species in their catalogue of 1871, Schenkling listed 1000 species in the Catalogus Coleopterum of 1906, while Wagner (1912) himself listed some 1075 species. According to Phelps (1955), Balfour-Brown of the British Museum of Natural History possessed records of some 2500 species in 1955.

The practice of dividing apionid genera into subgenera began before the turn of the century. Wagner (1908) classified Apion soleatum in the subgenus (Perapion). Kissinger (1968) in the most recent review of world genera listed 36 subgenera of the genus Apion. He arranged the subgenera in alphabetical order for convenience, adding that at that time there did not appear to be a logical way to arrange the subgenera since the necessary phylogenetic or cladistic data were not available.

Distinguishing characteristics of the genus were given in a key to world genera of Apioninae by Kissinger (1968). This key is widely recognised and modern authors merely alter couplets of the key when a revision demands additions (eg. Alonzo-Zarazaga 1984). Characteristics of the genus Apion include the following:

i. Claws free at base.

ii. Metatrochanter less than one third as long as metafemur.

iii. Head not constricted at base behind the posterior margin of the eye.

iv. Anterior margin of the prothorax lacking an obvious post-ocular lobe.

v. Mesothorax lacking a deep lateral pit near the posterior margin of the prothorax.

vi. Body lacking numerous, stout club-like setae.

vii. Paramere apical lobes generally lacking.

viii. Apical sclerotised plate bearing macrochaetae.

2.3 The species Apion soleatum Wagner

The type specimens were collected by G.A.K. Marshall in the then Salisbury, Rhodesia (now Harare, Zimbabwe), in 1902. These were forwarded to the British Museum of Natural History and were described by Wagner (1908) as follows:

" APION (PERAPION) SOLEATUM nov. spec.

Body black-brown, prothorax and elytra with reddish tint, antennal shaft (scape) and base of third segment reddish yellow. Body covered with short white hairs. Underside of tarsi in males densely covered with white hairs.

Head with eyes large and slightly convex, as long as wide (ie. circular). Vertex slightly convex and punctate. Rostrum relatively short and strong, in the male seemingly shorter, in the female nearly as long as the thorax, in both male and female the rostrum is expanded at the base and narrower apically. In the male the head is 'hairy' and densely punctate, in the female less 'hairy' and less densely punctate. Head

in female shinier. Antennae inserted near the base of the rostrum and are short and strong/stout ('kurz und kräftig'), shaft (scape) somewhat longer than the two subsequent segments together. Third antennal segment short and oval, more compact than following segments these being more closely joined ('eng aneinand gefügt'), in the male, the antenna more pointed than in the female.

Pronotum ('Halsschild') not as long as broad at the base, anteriorly slightly narrower. Posterior margin of prothorax weak, base only slightly constricted, on the sides only slightly rounded, posterior corners/angles of prothorax nearly right-angled ('Hinterecken nahezu rechtwinkelig'), the base slightly constricted and densely punctate, anterior to pronotum slight but distinct constriction present.

Elytra somewhat longer than one and one third times as wide, basally broader than the thorax, on the sides only slightly rounded, widest near the middle, posteriorly uniformly rounded, ridges broad and punctate, striations one and one half times as wide as ridges. Articulatory processes ('Schulterbeulen'), of elytra distinctive and elongate, triangularly shaped and furrowed with two distinctive processes. Legs short and oval, first and second tarsal segments approximately the same length, slightly longer than wide, tarsal claws bluntly serrate. In the male the ventral surface of the tarsi clothed with a dense hairpad ('Haarsohle bekleidet'), in the female the metasternum on each side of the

coxae lumpishly formed; the four posterior tibiae with a brush of black hairs apically which makes them appear wider than they are.

Length. 1.9 - 2.1 mill.

4 examples (2 males, 2 females) from Salisbury-Mashonaland (II. 1902, G.A.K. Marshall) presented for description."

Pearson (1958) in a checklist of pests of East Africa refers to A. soleatum and Apion xanthostylum Wagner as conspecific. According to Pearson (1958), both G.A.K.Marshall and Balfour-Brown informed him that the type of A. xanthostylum was indistinguishable from that of A. soleatum. The name soleatum is the older and therefore a synonymy. The type of A. xanthostylum was collected at Kaani, Tanganyika.

The examples of South African A. soleatum examined, all possessed a mesothoracic lateral pit near the posterior margin of the prothorax. In addition, the head bears a definite but slight constriction behind the posterior margin of the eye. These observations contrast with the characteristics of the genus Apion sensu Kissinger (1968).

Specimens of A. soleatum from South Africa have been compared with the type specimens in the British Museum of Natural History by Alonzo-Zarazaga (1988, pers. comm.), an authority on Ethiopian Apionidae. These were found to be conspecific. Alonzo-Zarazaga (1988, pers. comm.) considered that these South African specimens may represent a new genus, somewhat similar to Caenapion Voss. Furthermore he added that the genus Apion is considered to be exclusively palaearctic and that he would probably be erecting a new genus with the name Lonchaspis to cover the insect originally described as A.

soleatum (Appendix A). Although the insect being dealt with here is probably not an Apion, it will be referred to as Apion soleatum until a better name has been determined.

2.4 Species in the genus Apion Herbst of importance to mankind

In various parts of the world, other species of the genus Apion achieve pest status as well. Apion occidentale in the American states of North Dakota and Minnesota has been shown to transmit fungal diseases to sunflowers (Gaudet & Schulz 1981). Apion vorax in England was identified as the main vector of the broad bean stain and broad bean true mosaic viruses (Cockbain et al. 1982). In India, Apion corchori is a major pest of jute (Dutt & Ghatak 1979; Chalterji & Das 1979), while in Finland and elsewhere, several apionid species caused severe damage to clover seeds (Freeman 1967). This seed feeding habit has been used to man's advantage in several bio-control projects, for example Trichapion lativentre on Sesbania punicea in South Africa (Hoffman 1988) and Apion ulicis on gorse in New Zealand (Cowley 1983). Hopkins & Whittaker (1980a; 1980b) studied the population dynamics of two Apion spp. on two Rumex spp. (Polygonaceae). Kissinger (1967) reported the presence of Apion longirostre (Oliver) on cotton in the United States, although no mention was made of any economic losses as a result. This species is better known from hollyhock (Tattershall and Davidson 1954).

In Tanzania, A. soleatum was noted as a pest of cotton as long ago as 1922 (Ritchie 1922), while more recently Le Pelley (1959) included A. soleatum in a checklist of insect pests of East Africa, and Pearson (1958) briefly mentioned some biological aspects related to its life-cycle on cotton. Four species of Apion were included in a checklist of Mozambiquean pests of cotton in 1968

(Alcantara Santos 1990, pers. comm.). They were A. asphaltinum Wagner, A. consimile Wagner (a pest of coffee), A. constrictum ?, A. considerandum Fahraeus. Alcantara Santos also mentioned that the Mozambiquean INIA insect collection possessed specimens of A. xanthostylum collected from cotton between 1943 and 1956 (Appendix B).

Scientific literature concerning A. soleatum in South Africa does not exist. However a few informative articles have appeared in Co-operative's newsletters and information bulletins (e.g. Broodryk and Mansfield 1985, Niles and Greeff 1989). Additional information is contained in unpublished reports of T.C.R.I. entomologists, which indicate that A. soleatum occurs in the areas mentioned above (Bennett 1988, unpub. report; Eulitz 1987, unpub. report).

CHAPTER 3. THE DISTRIBUTION OF Apion soleatum IN THE COTTON PRODUCING REGIONS OF SOUTH AFRICA

3.1 Aims and methods

The cotton producing areas in South Africa were recently categorised into eight main regions, comprising a total of fifty magisterial districts and based on the variation in length of the growing season in each (Dippenaar 1988). These regions were Lower Orange River, Northern Cape, Western Transvaal, Northwestern Transvaal, Limpopo Valley, Central Transvaal, Eastern Transvaal and Northern Natal (Fig. 3). Each of these regions, with the exception of the Lower Orange River, was visited on several occasions during the 1987/88, 1988/89, 1989/90 and the first part of the 1990/1991 seasons. In each of these regions surveys were made at various producer and experimental farms. The aim of the survey was to determine where A. soleatum occurred in South African cotton, and also to determine if its distribution was increasing.

A simple sampling method was chosen, which conformed closely with present day scouting practices. The official recommendation with respect to the application of pesticides to cotton is based on the "scouting" technique, first described by Matthews and Tunstall (1964), and formalised by Basson (1987). The underlying principle is the sampling of 24 cotton plants in a field and the recording of the numbers of pest species present. Should this quantity exceed the previously determined economic threshold, the relevant insecticides are applied. The 24 plants that are sampled are chosen by walking a diagonal path through the field in question and randomly selecting the plants. This method was utilised, firstly

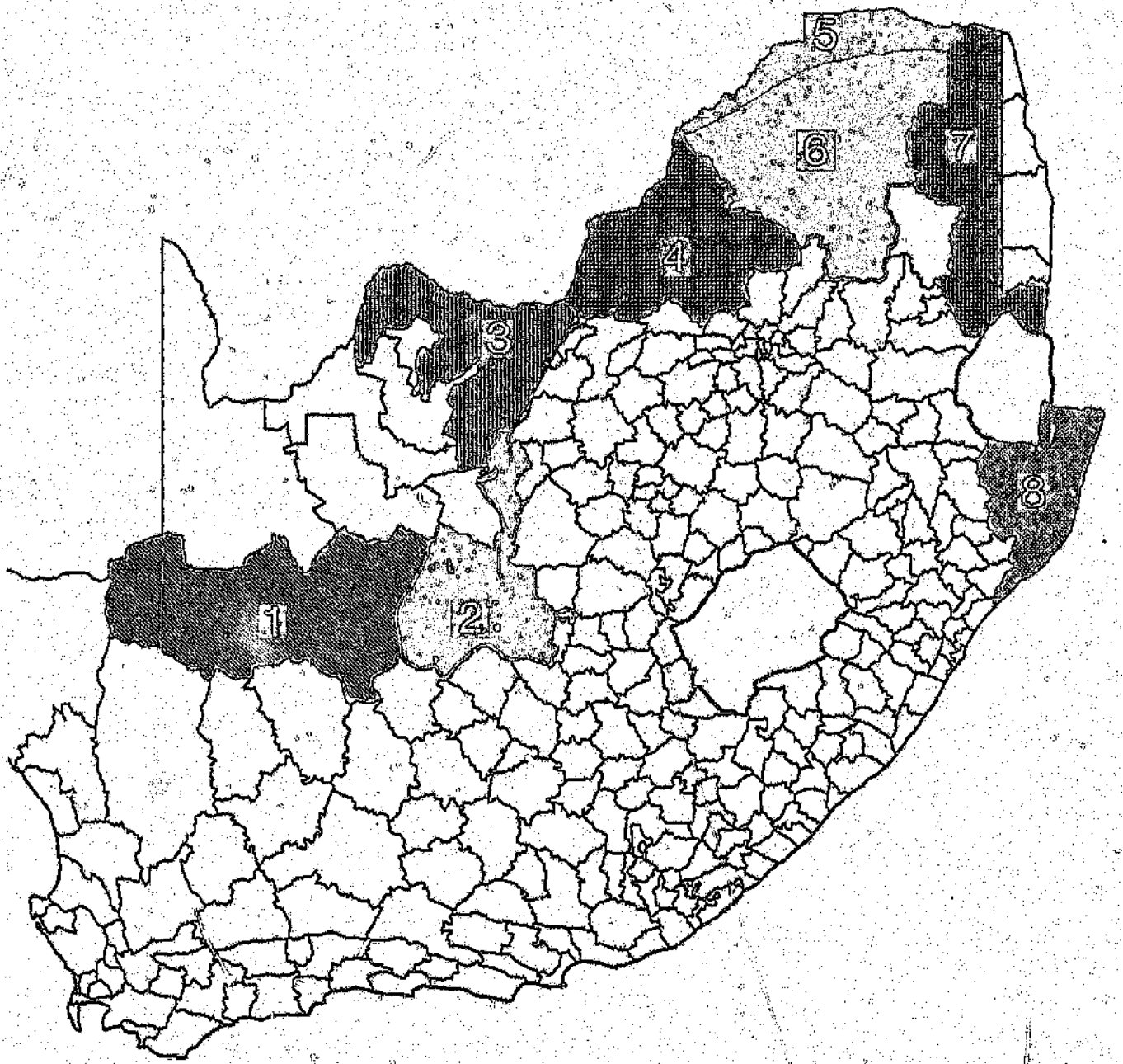


Fig. 3 Cotton producing regions of South Africa.
1. Lower Orange River 2. Northern Cape 3. Western Transvaal 4. Northwestern Transvaal 5. Limpopo Valley 6. Central Transvaal 7. Eastern Transvaal 8. Northern Natal

because it is a recognised sampling method in cotton and secondly because it was very easy to apply. The only difference was that 25 plants were sampled. In counting adults care had to be exercised not to disturb the plant being sampled, otherwise the adults fell to the ground and were impossible to observe. Larval and pupal data were obtained by splitting stems open and checking for damage in the form of a characteristic reddish brown stain. If the staining was observed, the plants were subjected to a more careful investigation. The areas were visited at irregular intervals, with the exception of Hoechst's research farm near Malelane, because transport arrangements were such that trips to these areas had to be shared with other personnel at the T.C.R.I.

3.2 Results

The results of the survey are presented in Tables 1-4. A. soleatum occurs only in the Northern Natal and Eastern Transvaal regions. In Northern Natal, the insect had a wide distribution, being recovered from cotton near Pongola, Mkuze and on the eastern side of the Lebombo Mountains in the Makatini Flats. In the Eastern Transvaal, the distribution of A. soleatum was localised, being found at only one locality other than Malelane.

Table 1. Apion soleatum survey in Northern Natal and Eastern Transvaal

AREAS	DATES	LOCATIONS	PLANTS	ADULT	PUPAE	LARVAE	TOTAL
NORTHERN NATAL							
Pongola/Mkuze	4-5.8.88	12	160	47	4	25	76
Mkuze	19.07.89	1	25	17	9	27	53
	01.02.90	3	75	0	0	0	0
Pongola	19.07.89	2	50	9	5	15	29
	01.02.90	1	25	23	16	31	70
	08.03.90	2	50	14	10	23	47
Makatini/Mjindi	08.03.90	3	150	156	121	754	1031
Estates	21.11.90	1	25	25	0	0	25
	08.01.91	1	25	0	26	15	41
EASTERN TRANSVAAL							
Malelane	13.09.88	1	25	270	69	573	912
	14.10.88	1	25	287	77	621	985
	10.11.88	1	25	362	119	7	1274
	08.12.88	1	25	310	105	86	1279
	12.01.89	2	50	94	45	598	737
	27.02.89	1	25	35	45	87	167
	11.05.89	1	25	0	0	0	0
	11.01.90	1	25	0	0	0	0
	09.03.90	1	25	0	0	0	0
	02.10.90	1	25	11	6	18	35
Letsitele	23.03.89	2	50	0	0	0	0
	06.02.90	2	50	0	0	0	0
Hectorspruit	11.01.90	4	100	0	0	0	0
Komatipoort	11.01.90	2	50	0	0	0	0
Figtree	11.05.89	4	170	2	0	0	2
Burgersfort	12.05.89	2	200	0	0	0	0

Table 2. Apion soleatum survey in the Limpopo valley, Central, Northwestern and Western Transvaal regions.

AREAS	DATES	LOCATIONS	PLANTS	ADULT	PUPAE	LARVAE	TOTAL
LIMPOPO VALLEY							
Weipe	21.03.89	1	25	0	0	0	0
	25.02.91	4	100	0	0	0	0
Pontdrif	21.03.89	2	50	0	0	0	0
	25.03.91	2	50	0	0	0	0
Messina	06.02.90	4	200	0	0	0	0
	11.04.90	2	100	0	0	0	0
CENTRAL TRANSVAAL							
Toowoomba	22.12.88	2	50	0	0	0	0
	18.01.89	2	50	0	0	0	0
	20.03.89	1	25	0	0	0	0
	05.02.90	2	50	0	0	0	0
	12.04.90	2	50	0	0	0	0
	26.01.91	4	100	0	0	0	0
Potgieterus	20.03.89	1	25	0	0	0	0
	05.02.90	2	50	0	0	0	0
	12.04.90	2	50	0	0	0	0
Groblersdal	17.01.90	2	50	0	0	0	0
	07.02.90	2	50	0	0	0	0
Oudestad	07.02.90	2	50	0	0	0	0
Springbok Flats	23.03.89	3	150	0	0	0	0
NORTH WESTERN TVL							
Rustenburg	weekly	2	-	0	0	0	0

Table 3. Apion soleatum survey in the Northern Cape.

AREAS	DATES	LOCATIONS	PLANTS	ADULT	PUPAE	LARVAE	TOTAL
NORTHERN CAPE							
Vaalharts	06.02.89	1	25	0	0	0	0
	14.02.90	2	50	0	0	0	0
Rietrivier	07.02.89	1	25	0	0	0	
	14.02.90	1	25	0	0	0	
Douglas	07.02.89	2	50	0	0	0	0
Sandvet	08.02.89	1	25	0	0	0	0
WESTERN TRANSVAAL							
Schweizer-Reneke	02.08.89	1	25	0	0	0	0

Table 4. Total numbers of Apion soleatum recovered over study period.

AREAS	ADULTS	PUPAE	LARVAE	TOTAL
NORTHERN NATAL	291	191	890	1 372
EASTERN TRANSVAAL	1 371	466	3 554	5 391
LIMPOPO VALLEY	0	0	0	0
CENTRAL TRANSVAAL	0	0	0	0
NORTHWESTERN TVL	0	0	0	0
WESTERN TRANSVAAL	0		0	0
NORTHERN CAPE	0	0	0	0
TOTAL	1 662	657	4 444	6 763

3.3 Discussion

A. soleatum would appear to be confined to the eastern cotton producing regions of South Africa. According to the Annual Report of the Cotton Board for 1989/90, 11 275 ha of cotton was planted in Northern Natal which comprised approximately 10.5 percent of the years production. In the Eastern Transvaal, 2000 ha of cotton was planted, which produced approximately one percent of the country's harvest. These two regions together produce approximately 12 percent of South Africa's cotton. The threat to the industry posed by A. soleatum is thus minimal, however cotton producers in these two regions are threatened. In both Northern Natal and the Eastern Transvaal, more and more sugar is being produced at the expense of cotton. This trend has resulted in the cotton gin at Heatorspruit in the Eastern Transvaal being moved to Settlers. It is not contended that these trends have been as a result of A. soleatum, but this pest has contributed to the current state of affairs.

CHAPTER 4. THE MORPHOLOGY OF *Apion soleatum*

4.1 Introduction

For the solution of any problem in economic entomology, an intimate knowledge of the morphology of the insect pest is essential. Often the basis for methods of control are indicated by a thorough knowledge of the morphology of the species concerned (Headlee 1930). More recently, Samways (1981), has stated that the biological control researcher must be a "thoroughly good naturalist", and that taxonomic mistakes are often costly in terms of time and money. Obviously, a thorough knowledge of the insect in question, beginning with its morphology is essential.

In this work, the larva and adult have received most attention, since they are the damaging stages. In the case of the larva, the terminology of Anderson (1947) was followed as closely as possible, since most authors appear to use it. In some cases where confusion existed, eg. the spiracles, alternative suggestions have been made. The description of the thorax and the abdomen refer to one longitudinal half of the larva. The works of Phelps (1956a) and Maldwyn-Davies (1928) have been heavily consulted, since they both undertook detailed descriptions of closely allied species.

The works of Snodgrass (1935) and Phelps (1956a) were followed with respect to terminology in the case of the adult. Where controversy and confusion occurred, the works of Crowson (1981), DuPorte (1960), Edmonds (1972), Imms (1957), Nel and DeVilliers (1988) and Van Den Berg (1972) were consulted.

4.2 The larva

4.2.1 Materials and methods

Morphological work on the larvae was carried out on mature field collected specimens. Larval heads were prepared by boiling in 10 percent potassium hydroxide and neutralising with glacial acetic acid. They were then transferred directly to glycerine where the mouthparts were dissected out under a stereo dissection microscope. Dehydration in a graded alcohol series followed, whereafter 'infiltration' in a graded ethanol/xylene series occurred. Permanent mounts were made using Entellan rapid mounting medium. Drawings were made using a high power compound microscope fitted with a drawing tube.

Whole larvae were prepared by immersion in warm potassium hydroxide until they started to lose colour. Transfer to glycerine after neutralising then took place. Slides were prepared by affixing two un-crimped staples, end to end, on the glass with molten candle wax. Larvae were placed in this 'enclosure' in glycerine, and a cover slip was placed over the staples. This ensured that the larvae could be examined under the compound microscope at high magnifications, without distortion (of the larvae) occurring. Drawings were made in the same way as mentioned earlier.

4.2.2 General appearance

Larvae of A. soleatum are fleshy, creamy-white, apodous grubs, which exhibit the general crescentic form of curculionoids (Fig. 4). A few scattered setae occur on the head and body, the latter being covered with asperities. The head,

thorax and abdomen are clearly demarcated and the descriptions of each of these tagmata follows:

4.2.3 The Head and Trophi

The head capsule of the mature larva is a rich golden brown colour which when viewed from an anterior aspect assumes a roughly circular outline (Fig. 5). The diameter of the mature head is considerably less than that of the prothorax, measuring between 0.4 and 0.5 mm and varies slightly between individuals. The relative position of the mouthparts to the head capsule is intermediate between the hypognathous and prognathous states. The antennae are minute and contrary to those of Piezotrachelus varium (Wagner) (Phelps 1956a) comprise only a single visible segment. Associated with each antenna are two fine setae.

According to Böving and Craighead (1931), apionid larvae possess a single ocellus on each side of the head. Chapman (1982) states that the absence of a single, thickened cuticular lens indicates the absence of ocelli (dorsal ocelli). In A. soleatum, however, stemmata as evidenced by small yet distinct areas of pigmentation adjacent to the distal ends of the frontal sutures, are present. Neither Wagner (1912) nor Maldwyn-Davies (1928) report the presence of ocelli in the Apioninae and A. ulicis Fort respectively, however both Phelps (1956a) and Servadei (1940) mention the presence of pigment spots in P. varium and Apion apricans Herbst respectively. In the latter two species these were referred to as ocelli, but were probably stemmata. In A. soleatum a single stemma (Fig. 5, st) is present on each side of the head.

Both the frontal (Fig. 5, f.s) and coronal sutures (Fig. 5, c.s) are prominent and the epicranial plates which they bound, large. The frontal suture does not

attain the mandibular articulation. Three pairs of frontal setae (Fig. 5, f.set) occur on the frons together with three sensilla (Fig. 5, sen). The two more ventral pairs of setae are approximately equal in length, while the more dorsal pair is conspicuously shorter. Four pairs of dorsal epicranial setae (Fig. 5, d.e.set) are present together with a single pair of lateral epicranial setae (Fig. 5, l.e.set) and posterior epicranial setae (Fig. 5, p.e.set). The posterior epicranial setae are short and inconspicuous. Five pairs of visible sensilla occur on the genae.

The clypeus (Fig. 6a) is distinctly separated from the frons by the epistomal suture (Fig. 6a, e.s). The part of the frons adjacent to the clypeus is heavily sclerotised, somewhat bow shaped and has a conspicuous plate-like appearance. The clypeus itself is approximately twice the size of the labrum and measures some 0.08 mm basally. It bears a single pair of basally situated clypeal setae (Fig. 6a, c.set), together with a pair of clypeal sensilla (Fig. 6a, c.sen).

Labrum and epipharynx: The labrum (Fig. 6a) is exceptionally small, measuring some 0.02 mm x 0.05 mm, and is clearly demarcated from the clypeus by the clypeo-labral suture (Fig. 6a, c-l.s). Three pairs of labral setae (Fig. 6a, l.set) are located dorsally. Labral sensilla are not evident. The epipharynx is fused to the ventral surface of the labrum, and according to both Phelps (1956a) and Crowson (1981) bears features, the character of which are important taxonomically. In ventral aspect (Fig. 6b) the labrum is triangular in outline. Three pairs of antero-lateral epipharyngeal setae (Fig. 6b, al.set) are present, together with three pairs of smaller antero-median epipharyngeal seta (Fig. 6b, am.set). These six pairs of setae are all curiously club-shaped, a feature not found commonly amongst larval Curculionoidea

(Oberprieler 1989, pers. comm.). In P. varium (Phelps 1956a) and A. ulicis (Maldwyn-Davies 1928), these setae, while stout in form, are still apically pointed. A pair of heavily sclerotised labral rods (Fig. 6b, l.r) originate centrally on the epipharynx, and project posteriorly over the clypeus. The labral rods are thickest proximally and taper off distally. A single pair of medial epipharyngeal setae (Fig. 6b, m.set), also club-shaped, are situated adjacent to the origin of the labral rods.

Mandibles: The mandibles are triangular in shape (Fig. 7) and bear apically three distal mandibular teeth (Fig. 7, d.md.te). The apical and medial teeth are conspicuous whereas the inner, proximal tooth is barely noticeable. Evidence for its presence include the fact that the adult mandible is conspicuously tridentate, the presence, when viewed ventrally, of a fine but distinct groove separating the tooth from the molar region (Fig. 7, mo), and the fact that other apionids, namely P. varium (Phelps 1956a) and A. ulicis (Maldwyn-Davies 1928), also possess tridentate mandibles. The postartis (Fig. 7, poart) or ventral articulatory condyle, is prominent. The preartis (Fig. 7, preart), or dorsal articulation, is not as noticeable, but is evidenced by a shallow, heavily sclerotised concavity which articulates against the ventral surface of the frons. The mandibular adductor muscle (Fig. 7, md.ad) is much larger than the mandibular abductor muscle (Fig. 7, md.ab). In dorsal aspect two mandibular setae (Fig. 7, md.set) are visible, while a further circularly shaped structure is also present. Phelps (1956a) referred to this as a mandibular seta in P. varium. All A. soleatum specimens examined possessed this structure and in all cases no seta was evident. It is suggested that this structure is possibly a sensillum. Crowson (1981) mentions the presence of mandibular sensilla in larval Histeridae. Amongst the Curculionoidea, Van n Berg (1972) noted the presence of larval mandibular sensilla in Eremnus cerealis Marshall,

and Van Emden (1938), while not referring to mandibular sensilla in his text, included them in drawings of the mandibles of larvae of the genera Rhynchites (Attelabidae) and Apoderus (Apoderinae).

Maxillae: The maxillae are loosely fused to the labium by means of lightly sclerotised membranous tissue. However they are quite distinct and will be treated separately. The cardo (Fig. 8, ca) is elongate and possesses a heavily sclerotised margin, the distal end of which articulates with a similarly sclerotised region (Fig. 8, scl.r) on the stipes (Fig. 8, st). The stipes is markedly elongate and bears a single lateral stipetal seta (Fig. 8, l.st.set). The galea and lacinia are fused to form a mala (Fig. 8, ml), which itself is fused with the stipes. Between the stipes and the mala there are no demarcating structures. The mala bears five paddle-like dorsal malar setae (Fig. 8, d.ml.set) and a single ventral malar seta (Fig. 8, v.ml.set). The dorsal malar setae, being curiously paddle-shaped, are like the epipharyngeal setae in that they seldom occur among the curculionoids (Oberprieler 1989, pers. comm.). A single dorsal malar sensillum (Fig. 8, d.ml.sen) is present and is situated slightly proximal to the bases of the dorsal malar setae. The mala further bears numerous small indistinct spines on the mesal margin, roughly opposite to the insertion of the maxillary palpus (Fig. 8, mx.plp). These spines are termed mesal malar spines (Fig. 8, m.ml.spn). The palpifer (Fig. 8, pf) is somewhat indistinct, but bears a single palpiferal seta (Fig. 8, pf.set) basally and no sensilla. The two segmented maxillary palpus bears a single maxillary palpal seta (Fig. 8, mx.plp.set) on the basal segment. The distal segment is marginally longer than the basal one and neither bear any visible sensilla. In addition, the distal segment possesses an indeterminate number of minute maxillary conical papillae (Fig. 8, mx.con).

Labium: The labium (Fig. 9) is a largely membranous structure which is divided into two regions, the postmentum (Fig. 9, po) and the prementum (Fig. 9, pr). The postmentum is large and bears two pairs of postmental setae (Fig. 9, po.set), which are approximately equal in length. The prementum comprises a Y-shaped premental sclerite (Fig. 9, pr.scl) and an anterior membranous region. The premental sclerite appears to bear two pairs of sensilla (Fig. 9, drawn in but not labelled). Owing to the small size of the sclerite, these sensilla could not be clearly identified as such. The anterior membranous region of the prementum bears two pairs of small premental setae (Fig. 9, pr.set), the distal pair appearing to be slightly longer than the proximal pair. Further, a pair of one segmented labial palpi (Fig. 9, la.plp) is present. The labial palpi, as with the maxillary palpi, also possess an indeterminate number of minute labial conical papillae (Fig. 9, la.con).

4.2.4 The Thorax

The three segments comprising the thorax are easily distinguishable (Fig. 4, 1-3). Four regions can be recognised on each segment when viewed laterally. Dorsally each segment possesses a transverse fold (Fig. 4, tf), which divides the dorsum into an anterior predorsum (Fig. 4, pr) and a posterior postdorsum (Fig. 4, po). Ventral to the dorsum, the epipleurum (Fig. 4, eg. ep2) is found, variously developed in each of the segments. In the prothorax, it is separated from the postdorsum by a partial fold, whereas in the meso- and metathorax, it is more clearly demarcated. Ventrally, the pleura (Fig. 4, eg. p2) are large conspicuous sclerites, which are separated from the epipleura by well developed pleural grooves (Fig.4, pg).

The predorsum of the prothorax bears (in lateral aspect) four setae dorsally. The postdorsum bears five setae arranged on a dorso-ventral line. Two setae are borne on the predorsum of both the meso- and metathorax, a longer one near the midline, and a very small one postero-ventrally. The metapostdorsum possesses four setae arranged in a similar way to those of the mesopostdorsum.

A single annular-bicameral spiracle (Fig 4., sl; Fig. 10) associated with three setae is present and appears to be situated on the proepipleurum (a description of the spiracles follows elsewhere). The mesoepipleurum (Fig. 4, ep2) bears two posteriorly directed setae, while the metaepipleurum bears a single annular-bicameral spiracle, with which no setae are associated. Three setae are situated on each of the thoracic pleura (Fig. 4, eg. p2) and are associated with prominent, sclerotised plate-like convexities.

4.2.5 The Abdomen

This consists of 10 segments (Fig. 4, 4-13), of which the first seven bear annular-unicameral spiracles (Fig. 4, eg. sl0; Fig. 11). Abdominal segments one to eight (Fig. 4, 4-11) are basically uniform in structure, differing only in size and, in the case of the eighth segment, the absence of spiracles. In lateral aspect, five regions can be distinguished on each of these segments. Dorsally, a transverse fold separates the predorsum from the postdorsum, which bear a similar arrangement of setae as the meta pre- and post dorsum respectively. The dorsal margins of the abdominal epipleura (Fig. 4, eg. ep4) are demarcated by variously developed partial folds in the cuticle, while well developed pleural grooves (Fig. 4, pg) separate the same from the pleura. The abdominal sterna (Fig. 4, eg. st5) are located ventrally and are separated from the pleura by hypopleural grooves (Fig. 4, hpg). The ninth abdominal

segment is small by comparison and appears to possess only three setae, one situated dorsally and two medially. The very reduced tenth segment, with the anus (Fig. 4, a) at its apex, bears two setae dorsally and two ventrally.

4.2.6 Spiracles

The spiracles of A. soleatum are very similar in structure to those described for A. ulicis (Maldwyn-Davies 1928) and P. varium (Phelps 1956a). Maldwyn-Davies (1928) used the term 'biforous' (Fig. 12f) to describe the thoracic spiracles and 'normal' or 'not biforous' (Fig. 12g) to describe the abdominal spiracles. The spiracles of P. varium, both thoracic and abdominal, conform to the 'not biforous' type, and Phelps (1956a) used the term 'unicameral' (Fig. 12h) (Anderson 1947) to describe them, because they possessed a single lateral air tube.

Confusion in spiracular terminology arises when articles by other authors are considered. Snodgrass (1935) states that the term 'biforus' was originally introduced to describe a spiracle with two openings to the atmosphere. He then proceeded to distinguish between a 'true biforus' and a 'so called biforus' spiracle. These two terms, together with 'annular-biforous' (Peterson 1951), 'annular-bicameral' (Fig. 12e) (Van den Berg 1972) and 'bicameral' (Fig. 12b) (Crowson 1981) have been used to describe spiracles in which the atrial orifice is not entirely annular or circular. 'Biforous' (Fig. 12c) sensu Crowson (1981) refers to the original description, ie. a spiracle with two openings (Fig 12). Snodgrass's (1935) point that a thorough investigation of spiracular form is an absolute necessity, remains true.

It would therefore appear that the authors mentioned above have, to a lesser or greater degree, confused the terminology to such an extent that only a drawing of the spiracle can accurately convey to the reader its structure. In an attempt to rectify this problem (without confusing the issue further) it is suggested that the terms 'annular' (Fig. 12a), 'biforous' (Fig. 12c), 'bifid' (Fig. 12c) and 'cribiform' (Fig. 12d) be used to describe the form of the atrial orifice, while the terms 'acameral', 'unicameral', 'bicameral' etc. be used to denote the presence or absence, and number of lateral air tubes. Using this system, the thoracic spiracles of A. soleatum would be described as annular-bicameral, while those of P. varium and the abdominal spiracles of A. soleatum would be described as annular-unicameral.

The spiracles of A. soleatum larvae are minute structures (Fig. 10 and Fig. 11). The spiracle consists of a peritreme, a well developed atrium, lateral air tubes and an internal closing apparatus.

In both the thoracic and abdominal spiracles, the peritreme (Fig. 10, 11; p) is virtually transparent and is only evidenced by regions of thickened cuticle which appear as minute concentrically arranged folds in the cuticle surrounding the atrium (Fig. 10; Fig. 11, a). The atrium is heavily sclerotised, subglobose in shape and is situated subcuticularly. The atrial orifice (Fig. 10, Fig. 12, atr.o) is circular or annular in outline. In the thoracic spiracles two lateral air tubes (Fig. 10, l.a.t) open into the atrium, together with a trachea (Fig. 10, tr). The lateral air tubes are annularly thickened internally, there being five visible sclerotised ridges. Maldwyn-Davies (1928) referred to these ridges as trabeculae. To avoid confusion with the trabeculae in the scales of Lepidoptera and those in the atria of some spiracles (Imms 1957), it is suggested that these annulations be termed lateral air tube annulae (Fig. 10, l.a.t.a). In the

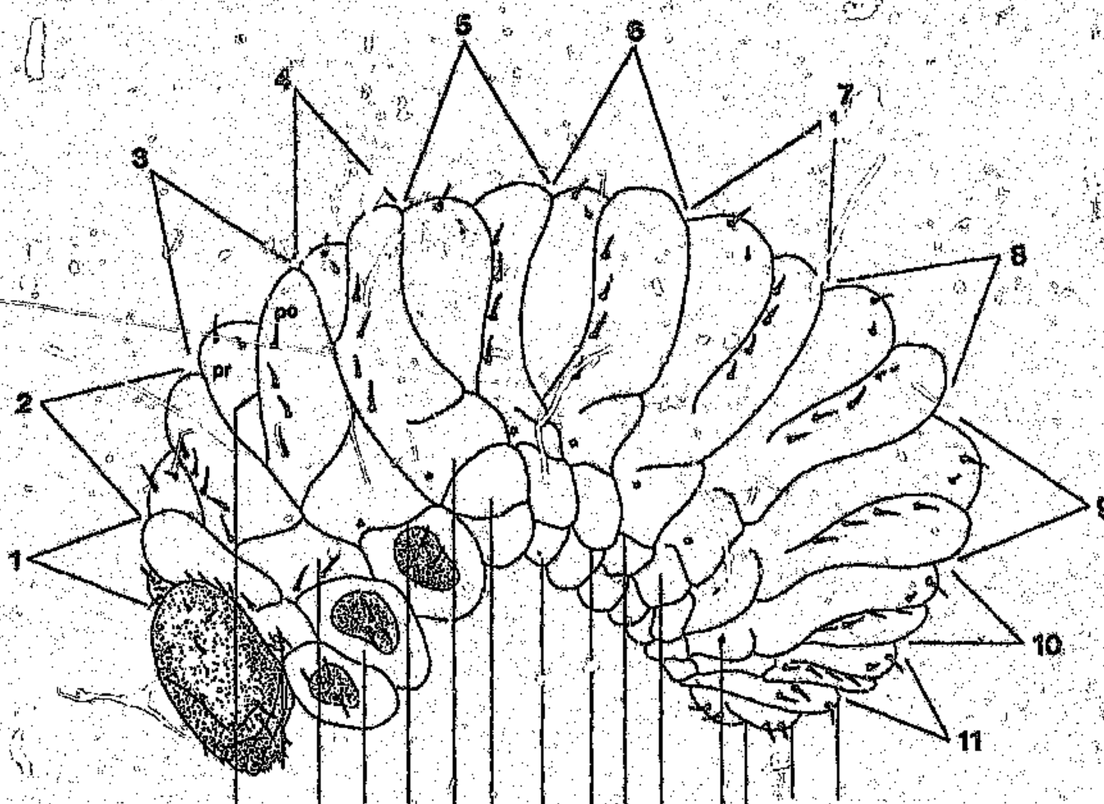
thoracic spiracles of A. soleatum one lateral air tube appears to overlay the other. The function of these tubes has not yet been elucidated. The abdominal spiracles possess a single lateral air tube (Fig. 11, l.a.t) which bears four visible lateral air tube annulae (Fig. 11, l.a.t.a). A single trachea opens into the atrium. The internal spiracular closing apparatus appears to be the same in both the thoracic and abdominal spiracles, and conforms to the simple pinchcock type described by Snodgrass (1935). It comprises a sclerotised bow (Fig. 10, 11, scl.b) associated with muscles which, when activated, close the trachea.

Fig. 4. Lateral aspect of mature larva of A. soleatum

1 prothorax, 2 mesothorax, 3 metathorax, 4-13 abdominal segments, a anus, epl 2 epipleurum of mesothorax, ep4 epipleurum of first abdominal segment, hpg hypopleural groove, pg pleural groove, p2 mesothoracic pleurum, p4 pleurum of first abdominal segment, p8 pleurum of fifth abdominal segment, pp postdorsum of metathorax, pr predorsum of metathorax, sl prothoracic spiracle, st5 sternum of second abdominal segment, sl0 spiracle of 5th abdominal segment, tf transverse fold.

Fig. 5. Anterior aspect of head of mature larva of A. soleatum

cs coronal suture, d.e.set dorsal epicranial seta, fs frontal suture, f.set frontal seta, lbr.set labral seta, l.e.set lateral epicranial seta, p.e.set posterior epicranial seta, sen sensilla, st stemma.


1
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9
10
11
pr
po
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s4
st5
hpg
ng
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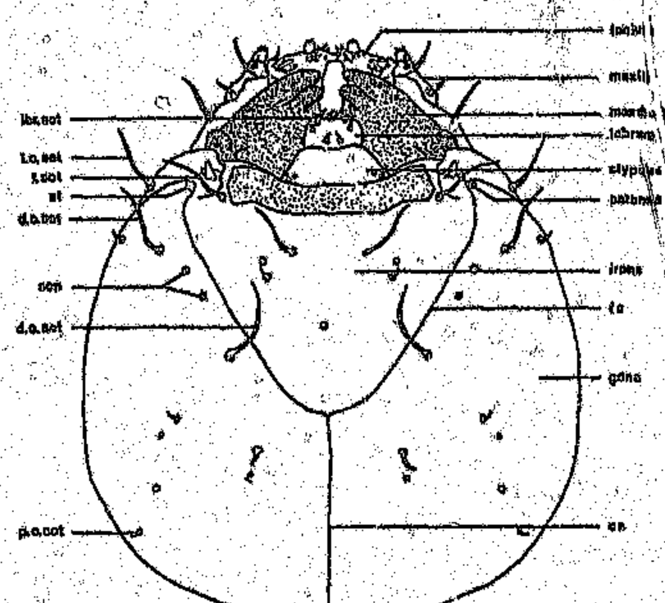
a
13
12
1.0 mm

4


clypeus
frons
gena
0.1 mm

5

Fig. 6a. Dorsal aspect of clypeus and labrum of mature larva of A. soleatum

c-l.s clypeo-labral suture, c.sen clypeal sensillum, c.set clypeal seta, e.s. epistomal suture, l.set labral setae.

Fig. 6b. Ventral aspect of clypeus and labrum of mature larva of A. soleatum

al.set anterolateral epipharyngeal setae, am.set anteromedian epipharyngeal setae, l.r. labral rod, m.set median epipharyngeal seta.

Fig. 7. Left mandible of mature larva of A. soleatum. a Ventral aspect. b

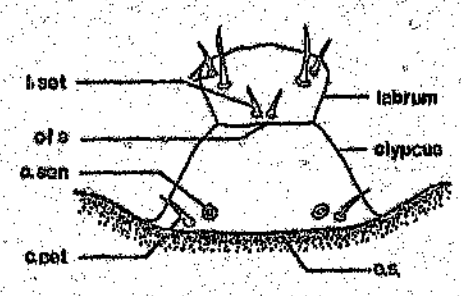
Dorsal aspect. d.c.e distal cutting edge, d.md.te distal mandibular teeth, md.ab mandibular abductor muscle, md.ad mandibular adductor muscle, md.set mandibular seta, mo molar region, poart postartis, preart preartis.

Fig. 8. Dorsal aspect of right maxilla of mature larva of A. solentum

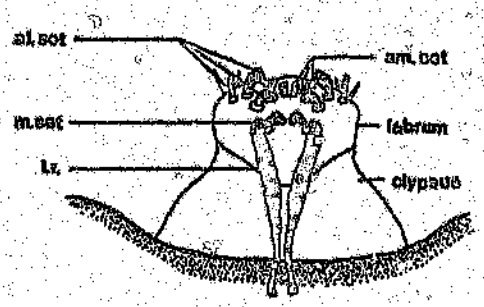
ca cardo, d.ml.sen dorsal malar sensillum, d.ml.set dorsal malar setae, l.st.set lateral stipetal seta, ml malar, m.ml.spn mesal malar spines, mx.con maxillary conical papillae, mx.plp maxillary palpus, mx.plp.set maxillary palpal seta, pf palpifer, pf. set palpiferal seta, scl.r sclerotised region, st stipes, v.ml.set ventral malar seta.

Fig. 9. Ventral aspect of labium of mature larva of A. soleatum

la.con labial conical papillae, la.plp labial palpus, po postmentum, po.set postmental setae, pr prementum, pr.scl premental sclerite, pr.set premental setae.



6 a



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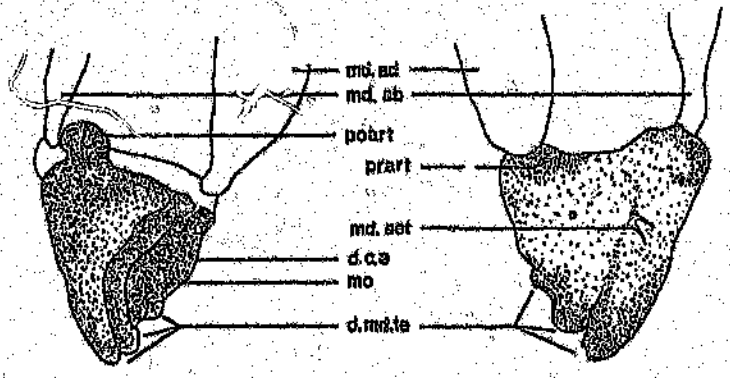
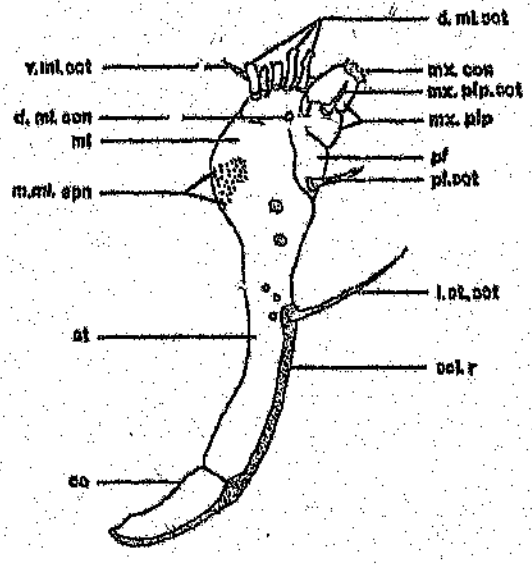
b



7 a

0.1 mm

b



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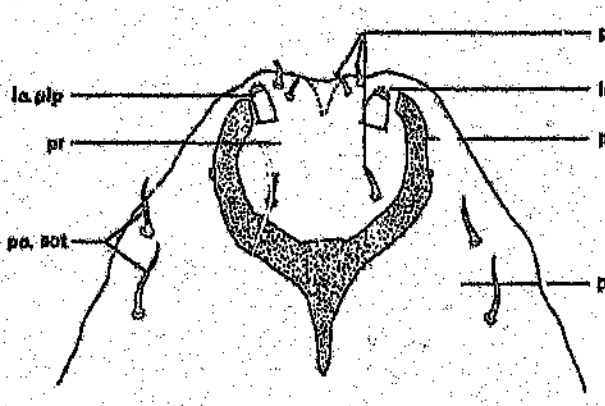
8



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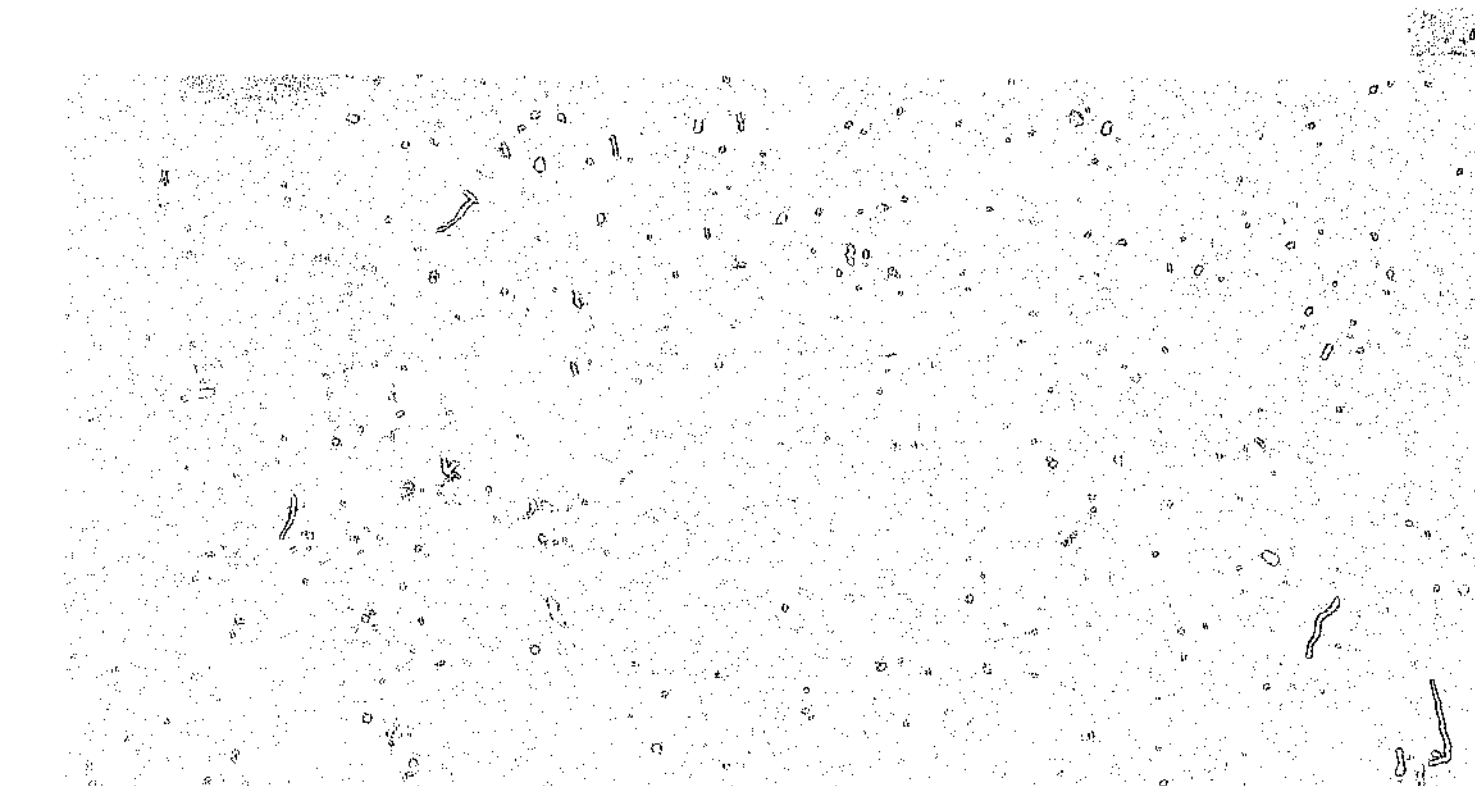


Fig. 10. Surface aspect of prothoracic spiracle of mature larva of A. soleatum

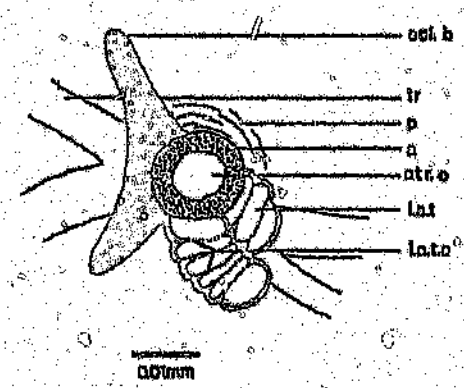
a atrium, atr.o atrial orifice, l.a.t lateral air tube, l.a.t.a lateral air tube annulae, p peritreme, scl.b sclerotised bow, tr trachea.

Fig. 11. Surface aspect of abdominal spiracle of mature larva of A. soleatum

atr.o atrial orifice, l.a.t lateral air tube, l.a.t.a lateral air tube annulae, p peritreme, scl.b sclerotised bow, tr trachea.

Fig. 12. Spiracular form and terminology in insects

a annular, b bicameral, c biforous sensu Crowson, d cribiform, e annular-bicameral, annular biforous, biforus, f biforous, g normal/not biforous, h unicameral.


oci. b
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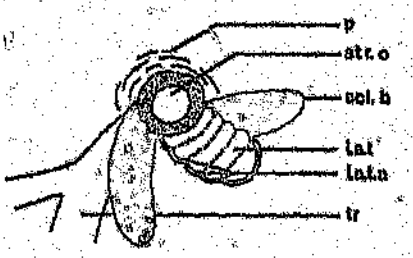
10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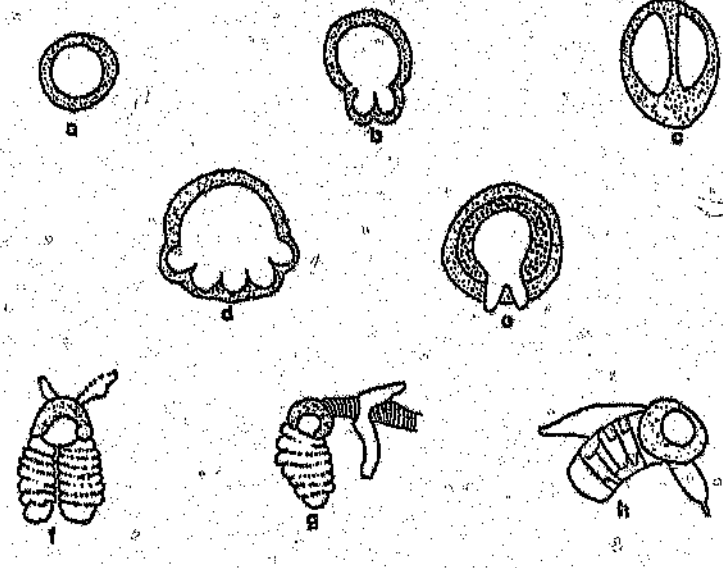
a
b
c
d
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f
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h

12

4.3 The pupa

4.3.1 Materials and methods

Field collected specimens were prepared in the same way as the larvae. Immersion in boiling ten percent potassium hydroxide was restricted to five minutes, otherwise the pupae tended to collapse, making them difficult to draw. In addition, boiling tended to displace the wings away from the body of the pupa.

4.3.2 Description

Young pupae of A. soleatum are creamy white in colour, becoming progressively darker as they mature and sclerotisation occurs. The eyes and mouthparts are the first structures to be sclerotised (see also Fig. 33). A. soleatum pupae closely resemble those of P. varium (Phelps 1956a) and A. ulicis (Maldwyn Davies 1928), being of the exarate type (Fig. 13). Length varies from approximately 2.0 mm to 3.0 mm. The head is reflexed ventrally and the rostrum (Fig. 13, r) is closely associated with the sterna of the thorax. The pupae of A. soleatum differ from those of A. ulicis (Maldwyn Davies 1928) and P. varium (Phelps 1956a) in that the rostrum is much shorter and does not extend to the sterna of the abdomen. Five setae are located on the pronotum. The antennae are well developed and are the scape, pedicel and club are clearly discernable (Fig. 13, a). They extend from the base of the rostrum in an antero-dorsal direction. The legs are all folded, the femur, tibia and tarsi being the most apparent in ventral aspect (Fig. 13; f, tb, t), while the trochanters and coxae are hidden beneath the rostrum. In A. soleatum, the metalegs are situated ventrad of the wings, whereas in A. ulicis (Maldwyn Davies 1928) and P. varium (Phelps 1956a), the wings are ventrad of the metalegs. The elytra (Fig. 13, el) are narrow and do not entirely cover the metathoracic

wings (Fig. 13, w). The thoracic segments are not clearly demarcated and in ventral aspect are hidden beneath the rostrum and tarsi. Ten abdominal segments occur, the sterna of which are easily seen in ventral aspect. In dorsal and lateral aspect the abdominal terga can be seen to resemble those of the larvae, each being divided by a transverse fold in the integument. The tenth abdominal segment is very much reduced, bears two caudal spines (Fig. 13, ca.spa) and the anus. The pupal integument (Fig. 13, pi) encloses the entire pupa and is clearly discernable.

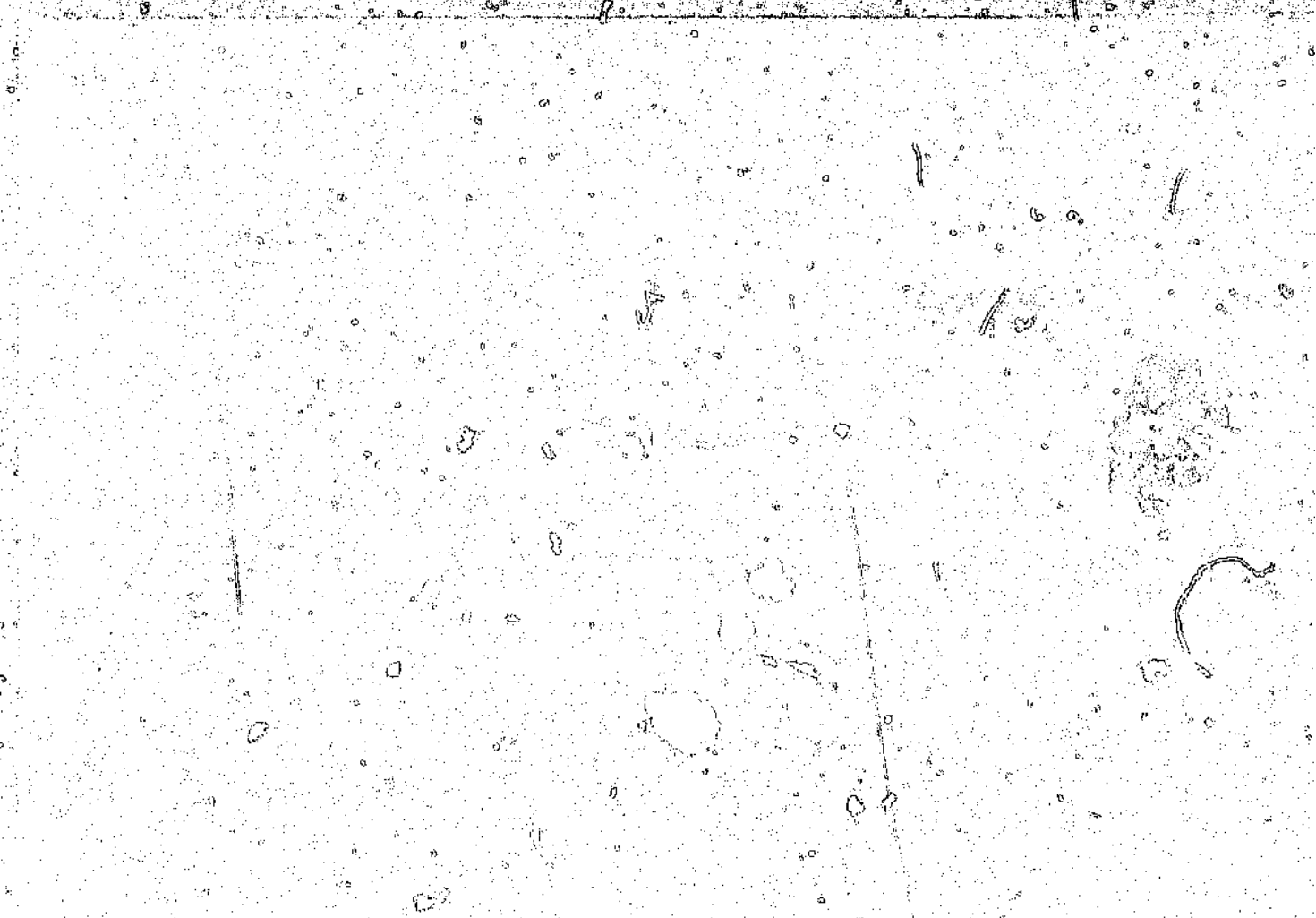
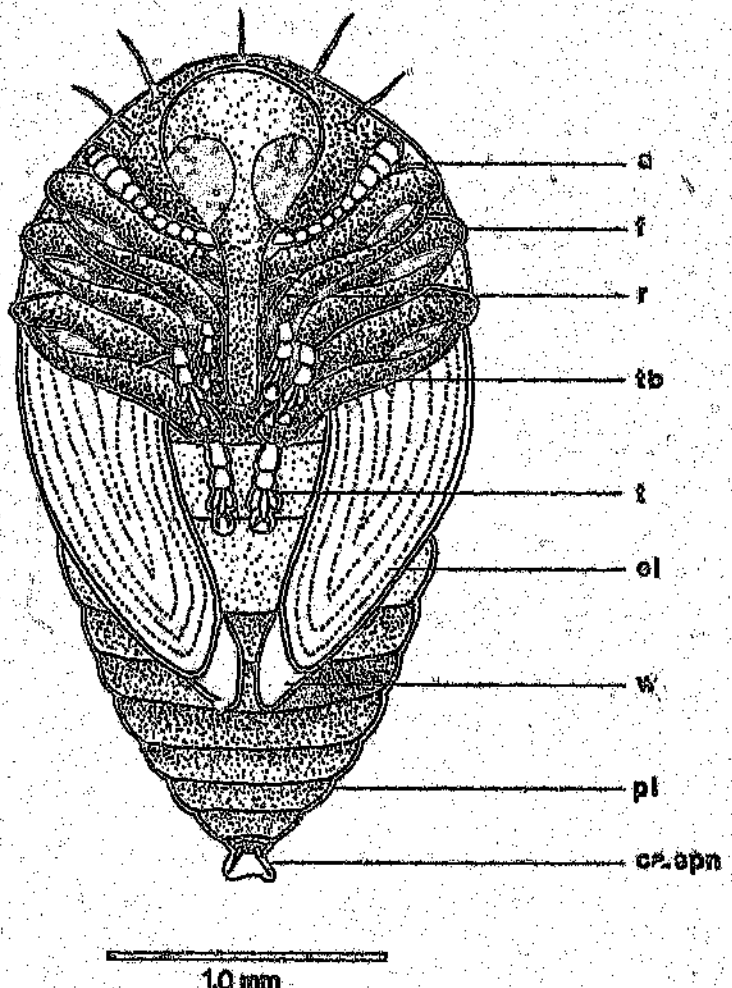


Fig. 13. Ventral aspect of pupa of A. sole[illegible]

a antenna, ca.spn caudal spin[illegible] elytron, f femur, pi pupal integument, r rostrum, t tarsus, tb tibia, w wing.



13

4.4 The adult

4.4.1 Materials and methods

Adults were collected from Northern Natal and from the Transvaal lowveld. Specimens were bleached in 20 percent hydrogen peroxide (Rees 1938) for examination of the general appearance and also of the sclerites of the thorax and abdomen. Bleaching permits observation of sutures which are normally difficult to observe because of the black colour of the insect. Mouthparts were prepared by decapitating specimens and immersing the heads in 10 percent boiling potassium hydroxide. Upon sufficient digestion of unsclerotised parts, the remaining head structure was neutralised with a few drops of acetic acid and placed in glycerine. Glycerine was found to be a better medium for dissection than alcohol as it prevented the mouthparts from moving about once dissected. Dissection took place under a stereo microscope, and the mouthparts were then subjected to dehydration in a graded alcohol series. This was followed by a xylene:alcohol series and permanent mounts were made using Entellan rapid mounting medium to affix cover slips. Staining with acid fuchsin was tried, but this did not improve resolution of structures. Drawings were made either under stereo or compound microscope, both fitted with a drawing tube. The length of scale bars was determined with the aid of a Zeiss calibration slide, which was marked in units of 0.05 mm.

4.4.2 General appearance

A. soleatum conforms well to the subfamily characteristics for Apioninae given by Wagner (1909), these being the following: abdomen with five visible sternites, sterna 1 and 2 broad, each at least as broad as sterna 3 and 4 combined, sternum 5 broad and flat and at least as broad as sterna 1 and 2, coxae of the metasternum separate, antennae straight and elytra completely covering the abdomen. The adult of A. soleatum also conforms well to the subfamily characteristics enumerated more recently by Kissinger (1968), namely tibia not uncinate (hook-shaped), antennae straight with funiculus (segments not comprising club or scape) seven segmented and mandibles not toothed on outer margin, antennal club compact, single gular suture, sternum 2 more or less equal to sterna 3 and 4 together, the suture between sterna 1 and 2 almost obliterated, tibiae simple without paired articulated processes apically and tergites only lightly sclerotised. In the discussion which follows it will become apparent that this species is indeed an apionid, but that its inclusion in the genus Apion is not well founded.

Adults exhibit some variation with respect to size, especially between the sexes, females being broader and slightly longer than males. Total length varies between 2.5 mm and 3.0 mm. Adults are black in colour when viewed with the naked eye, however on closer examination they can be seen to posses a faint reddish-brown tinge. The elytra are strongly convex and striated, and the body is almost entirely clothed with numerous white setae of variable shape and size. The integument is virtually completely sculptured, but this is only obvious under exceptionally high magnification. The rostrum is relatively stout and slightly curved, while the legs, because of their relative length, lend the insect an ungainly appearance (Fig. 14).

4.4.3 The Head and Trophi

The rostrum, formed by the anterior elongation of the facial sclerites constitutes the most striking feature of the head (Fig. 14). It bears the trophi at its apex and the antennae at its base. The antennal scapes are received in distinct scrobes. The compound eyes are large and convex. Contrary to P. varium (Phelps 1956a), the features associated with the identification of the ventral sclerites are distinct in A. soleatum.

In dorsal aspect the sutures marking the boundaries of the epicranial and frontal sclerites are absent. Posterior to the compound eyes a slight but definite constriction extends approximately half way down the parietal region of the head. This results in the parietals appearing "neck-like" (Figs. 14 & 16). The "neck" region is rounded and broader than the distance between the outer margins of the compound eyes. Adjacent to the circum-ocular suture (Fig. 14, cos), a ring of white setae is prominent. The eyes are separated at the vertex. The posterior region of the epicranium ("neck") folds inward, resulting in the occiput and occipital foramen possessing a much smaller circumference than that of the "neck". Caudad of the eyes, sculpturing in the form of numerous minute circum-cranial transverse ridges is present. The antennal insertions cannot be seen from the dorsal aspect, where the rostrum is widest. The rostrum narrows anteriorly.

At its apex an indistinct labrum is present (Fig. 15, lb). According to Oberprieler (1988) the terminology of the regions of the curculionid rostrum remains confused. Imms (1957) refers to the apex of the rostrum as the epistoma, a reduced fronto-clypeal region. Snodgrass (1935) states that the epistoma is another term for the upper part of the clypeus. Since then the apical part of

the rostrum has become generally known as the epistome (Fletcher 1965, Van Den Berg 1972, Oberprieler 1988) or the epistoma (Snodgrass 1935, Imms 1957). Phelps (1956a) uses the latter term for P. varium. In A. soleatum, however, the apical lobe bears certain features which suggest that it constitutes a labrum. According to Snodgrass (1935) the inner ventral surface of the labrum, when distinct from the membranous inner surface of the clypeus, is called the epipharynx. In addition, in the lateral angles between the labrum and the clypeus there generally occur a small pair of sclerites, the tormae, which extend into the epipharyngeal surface of the clypeus. Imms (1957) states that the labrum bears lateral sclerotised processes called tormae, while Nel and De Villiers (1988) refer to these structures as the "processus tormalis lateralis" or lateral tormal processes. The lateral tormal processes thus demarcate the clypeus from the labrum on the epipharyngeal surface. In A. soleatum a pair of lateral tormal processes (Fig. 15; 19, l.t.p.) are clearly discernable and the term labrum over epistoma is justifiable. The argument against the use of the term labrum is dependant on the absence of an externally visible epistomal (fronto-clypeal) suture, but since the lateral tormal processes indicate a ventral boundary between clypeus and labrum, this argument falls away. Anterior to the lateral tormal processes, a fringe of prostrate ridges which correspond in position to the lateral files (Edmonds 1972) and the pectines laterales (Nel and De Villiers 1988) of scarabaeids occur.

An examination of the part of the rostrum proximal to the labrum does not reveal either an epistomal suture or anterior tentorial pits. In fact no features occur between the labrum anteriorly and the occipital foramen posteriorly which identify the dorsal sclerites of the head. The dorsal part of the rostrum can therefore be termed the fronto-clypeus. The descriptive term epifrons (DuPorte 1960) is not considered appropriate since it refers to the median region

of the rostrum which bears the antennae. According to Snodgrass (1935), the parietals each bear an antenna, lateral, and beneath the eye, the parietal region corresponding to the genae. In the case of A. soleatum the antennae are borne on the suture between the genae and subgenae (Figs 15 & 16, a.s; Fig. 17, sc). With the elongation of the head sclerites to form the rostrum, the antennal sockets have moved forward but are still associated with the genae.

Ventrally, the sclerites of the head are all identifiable, contrary to those of P. varium (Phelps 1956a). Posterior tentorial pits (Fig. 16, p. ten) occur medially and ventrad of the hind most margins of the eyes (Fig. 16, c.e). The postoccipital or gular sutures (Fig. 16, F) are nearly confluent and lie medially between the posterior tentorial pits and the posterior of the head. As a result, the postocciput or gula is almost non-existent, a feature which conforms with the subfamily characteristic of Kissinger (1968). The postgenae (Figs 16 & 17, pg) occur laterad of the g[illegible]r suture and form the latero-ventral parts of the cranial sclerites. They are moderately convex and contribute to the neck-like appearance of the posterior of the head. The postgenae extend anteriorly below the ventral margin of the eyes and up to the hypostoma, forming the genae (Figs 16 & 17, g). The antennal sockets (Figs 15 & 16, a.s) are situated proximally on the subgenal sutures (Figs 15 & 16, B) in front of the eyes. The scrobes (Figs 14 & 17, sc) extend posteriorly to between the eyes, with the mesal margins of the scrobes forming a ridge confluent with the subgenal suture. Between the eyes, the subgenae (Fig. 17, sgn) coalesce in a depression which forms the posterior part of the scrobe. Anteriorly the subgenae support the hypostoma (Figs 15 16 & 17, hyp) which bears the mandibular precoilae and the maxillary articulation. The pterostomal suture (Figs 15 & 16, E) forms the boundary between the mandible and the hypostoma, while the

hypostomal suture (Figs 15 & 16, D) that between the maxilla and the hypostoma (Snodgrass 1935). These features are all visible in A. soleatum. The postmentum is situated between the subgenae (Figs 16 & 17, sgn), with the extended hypostomal suture forming the boundary between the postmentum and subgenae. Apically the labial suture (Figs 15 & 16, C) separates the postmentum and prementum, which together with the mandibles and maxillae are visible in ventral aspect.

Labrum and epipharynx: Dorsally, there is no indication of the presence of a labrum, the epistomal suture and anterior tentorial pits being absent or obliterated. As discussed earlier, there is sufficient evidence to term the apical dorsal lobe of the rostrum, a labrum. In A. soleatum, the labrum bears four large setae, the two lateral ones being slightly smaller than the medial two. Caudad of each of the setae, a single smaller seta occurs, approximately above the line between the lateral tormal processes internally (Fig. 18, l.set). On its ventral surface the labrum bears the epipharynx comprising the aforementioned lateral tormal processes (Fig. 19, l.t.p) and a membranous distal region bearing lateral files (Fig. 19, lf).

Mandibles: There appears to be no sexual dimorphism of the mandibles of adult A. soleatum, a feature common with P. varium (Phelps 1956a). Mandibular articulation in A. soleatum is facilitated by an apparently dorso-lateral depression and an apparently ventero-lateral condyle situated within an acetabulum. This contrasts with general mandibular structure among coleopterans, which posses a dorsal condyle and ventral acetabulum (Crowson 1981). With the development of the cylindrical rostrum and the accompanying modification in the position of the articulatory surfaces of the mandibles, the condyle articulation has become ventral in A. soleatum and other curculionids, but is in fact morphologically dorsal (Phelps 19.16a, Crowson 1981). While both left and right mandibles are virtually identical,

they are asymmetrically inserted, with the position of the left mandible distad to that of the of the right. The alignment of the articulatory surfaces is such that the mandibles move in an oblique plane permitting the gouging out of food material.

When viewed in ventero-lateral aspect (ie from within the rostrum), the dorsal articulation or preartis (Fig. 20, preart) can be observed to comprise a condyle (Fig. 20, c) surrounded by a deep acetabulum or ginglymus (Fig. 20, a). The articulation is completed with the precoilae of the hypostoma fitting into the acetabulum. The mandibular abductor muscle (Fig. 20, ab. m) is inserted distad of the preartis and is considerably smaller than the mandibular adductor muscle (Fig. 20, add. m). Phelps (1956a) states that it is the adductor muscle which is attached to the outer rim of the acetabulum in P. varium. This is an error, since a muscle inserted in such a position would only be capable of abduction. Maldwyn-Davies (1928) describes the mandibular muscles of A. ulicis correctly.

In dorso-lateral aspect (ie. viewed from the exterior), the mandible can be seen to posses a postartis (Fig. 21, poart) comprising a shallow depression on its ental surface. In addition, two subequal mandibular setae (Fig. 21, md. set) are present. Viewed from the exterior the mandibles appear to posses subsurface canals which run from the centre to the apexes of the teeth. These correspond in position to the grooves found on the mandibles of P. varium (Phelps 1956a).

The mandibles are tridentate, the distal and medial teeth (Fig. 20, dt; mt) being of approximately equal size and larger than the proximal tooth (Fig. 20, pt). The proximal tooth bears a broad cutting area which probably facilitates the gouging out of food material. A membranous pharyngeal bracon (Figs 20 & 21, ph. br), also known as the prostheca (Imms 1957), the prosteca modificata (Servadei 1940) and the pharyngeal process (Ting 1936) is present. Hopkins (1911) appears to have

authored the term "pharyngeal bracon" which was subsequently used by Maldwyn-Davies (1928) and Phelps (1956a). The pharyngeal bracon is clothed with posteriorly recurved papillae whose exact function is not clear. However, the bracons extend posteriorly into the pharynx and probably assist in conveying food material into the oesophagus (Maldwyn-Davies 1928, Phelps 1956a). In P. varium the bracons posses a sclerotised strip on their outer lateral margins (Phelps 1956a) but this is not the case in A. soleatum.

Maxillae: The maxillae are situated ventrally at the apex of the rostrum and slightly above and laterad of the labium. They move in a vertical plane as in other curculionids (Ting 1936). According to Ting (1936) the maxillae are rotated in position as a result of the development of the rostrum such that their morphologically dorsal surfaces are ventral and visible externally.

The ventero-lateral aspect illustrates the components of the maxilla well (Fig. 22). The cardo (Fig. 22, ca) is roughly V-shaped and proximally it articulates deep within the rostrum so that only the morphologically dorsal surface of the stipes is externally visible. Distally the cardo articulates with a narrow, elongate and well sclerotised stipes (Fig. 22, st). The stipes bears two stipetal setae (Fig. 22, st. set) on the external surface. The palpifer (Fig. 22, pf) is large and bears a two segmented maxillary palpus (Fig. 22, mx. plp), the distal segment of which bears at its apex approximately 10 conical papillae (Fig. 20, mx. con). Unlike P. varium, which possesses a single maxillary palpal seta (Phelps 1956a), none are borne on the palpus of A. soleatum. Caudad (in situ) of the palpifer and above the stipes is a relatively large sclerite which corresponds to the subgalea (Fig. 22, sg) of Pissodes strobi (Coleoptera: Curculionidae) (Hopkins 1911). The term subgalea is a controversial one yet it applies in A. soleatum. Snodgrass (1935) states that the subgalea is a lobe or subdivision of the stipes which bears the galea. Imms (1957)

defines the subgalea or parastipes as being a mesal (inner) sclerite of the stipes, which in many insects is not evident as a separate sclerite, being either fused with the lacinia or merged into the stipes. Ting (1936) asserts that the subgalea is absent in Rhynchophora. However, in A. soleatum the sclerite in question is well developed and cannot be confused as the galea, since by definition the galea is the outer endite lobe of the maxilla (Snodgrass 1935). In the case of A. soleatum this sclerite, while not directly abutting on to the stipes, is associated with the mesal surface of the lacinia or mala, indicating that it is indeed the subgalea. This opinion was also asserted by Phelps (1956a) concerning P. varium.

Articulating with the proximal, morphologically ventral part of the stipes is the lacinia (Fig. 22, lac) or mala of the maxilla. This is a membranous, approximately cone-shaped sclerite, which on its distal surface bears numerous posteriorly curved setae (Fig. 22, ml. set). Six curiously shaped, broad, blunt and recurved setae are also inserted on the posterior distal surface of the lacinia (Fig. 22,lac.t). Ting (1936) refers to these as lacinial teeth and found them to be present in Aglycyderus wollastoni Sharp (Aglycyderidae), Proterhinus maurus Perkins (Proterhinidae), Eupagoderes geminatus Horn (Otiorhynchidae) and Ithycerus noveboracensis (Forst) (Belidae). These setae vaguely resemble the larval malar setae (Fig. 8, d. ml. set) described earlier.

As with the subgalea, there is a lack of consensus concerning the composition of the malar lobe of the maxilla. Snodgrass (1935) makes no reference to a mala, but Das (19..) refers to the mala of coleopterous larvae being represented in some cases by the lacinia and in others by the galea. Ting (1936) states that the galea is the distal part of the lacinia, an opinion asserted more recently by Nel and De Villiers (1988) in an attempt to standardize scarabaeoid mouthpart terminology. Snodgrass (1935) on the other hand, refers to the galea and lacinia as two distinct

endite lobes of the maxilla, and Imms (1957) states that as a rule the lacinia is often associated with the subgalea, is spined or toothed and infers that the galea is not. In P. varium the malar lobe was considered to comprise the lacinia, because of the presence of many setae (Phelps 1956a). According to Nel and De Villiers (1988) the term mala refers to the fusion of the lacinia and galea. In A. soleatum it is not possible to see whether fusion between galea and lacinia has occurred, or whether the galea is completely reduced. Since this lobe is generously supplied with setae, the term lacinia is used, in common with Phelps (1956a).

Labium: According to Ting (1936), the labia of Rhynchophora comprise only two regions, namely the prementum and the postmentum. The postmentum represents the fusion of the submentum and mentum (Figs 15 & 16).

The prementum of A. soleatum is situated ventrally at the apex of the rostrum and between the maxillae. It comprises a rectangular lobe which bears the labial palpi (Figs 23 & 24, la. plp), the ligula (Figs 23 & 24, lg) and two premontal setae (Figs 23 & 24, pr. set). The labial palpi are one segmented and bear two labial palpal setae each (Fig. 23, la. plp. set) together with four to five labial condial papillae (Fig. 23, la. con). The premontal setae are inserted laterally, approximately half way along the length of the prementum.

In lateral aspect the ligula (Fig. 24, lg) is clearly discernable as a membranous structure associated with the dorsal surface of the prementum. The anterior apex of the ligula forms an apparently moveable lobe clothed in largely posteriorly directed ligular setae (Figs 23 & 24, lg. set). Posteriorly the ligula takes the form of a sclerotised arch (Figs 22 & 23, scl. ar) which appears to hold the membranous region erect. Both the labial palpi and ligular setae protrude beyond the margin of the prementum.

A clearly discernable labial suture separates the prementum from the postmentum (Figs 16 & 17, C). Generally, the postmentum appears as a ridge-like, raised region which may have been displaced ventrally by the subgenae during the development of the rostrum. It is well defined anteriorly and is associated with the hypostoma (Fig. 17, hyp). Although its posterior margins are not as distinct as they are illustrated, the postmentum appears to extend to between the compound eyes.

Antennae: The antennae of A. soleatum consist of 12 segments, which can be divided into three basic regions, namely the scape, pedicel and flagellum (Fig. 26, scp, p, f). The whole measures approximately 0.6 mm in length. The scape is the longest segment and bears two broad setae distally. The scape is also geniculate but this does not alter the straight form of the whole antenna. Proximally it articulates within a deep scrobe. The pedicel bears five curiously flattened and blunt setae mesally. The proximal five flagellomeres appear to bear two setae on their outer surfaces, and are of essentially the same shape and size. The sixth flagellomere gives rise to the antennal club, is much broader apically and appears to bear more setae than the preceding segments. The terminal four antennal segments comprise the club, the first two each bearing a ring of setae. The antennal club is also supplied with numerous sensory hairs.

4.4.4 The Thorax

The thorax of the adult bears several important generic characteristics. The anterior margin of the pronotum (Fig. 14, pn) in lateral aspect is slightly convex over its entire length. A post-ocular lobe (Fig. 14, po. l) is associated with the anterior margin of the prothorax, a feature which does not conform with the characteristics of the genus Apion. The posterior lateral margin of the pronotum

is slightly convex over the dorsal half of its length and slightly concave over the ventral half. As a result the latero-ventral emargination is shorter than that of the dorsal silhouette, and is bisected by a deep, oblique groove which runs into a lateral indentation. Dorsad of this indentation, its depth lessens as it curves upwards, almost approaching the anterior margin of the prothorax. The posterior angles of the pronotum are nearly orthogonal. The prothoracic coxae are large and protrude past the ventral margin of the lateral silhouette. The entire surface of the pronotum is covered with numerous anteriorly directed setae and the cuticle is sculptured with minute pits. The procoxal cavities are confluent in A. soleatum and there are no discernable sutures on the ventral surface of the prothorax.

In lateral aspect, the pterothorax is largely hidden beneath the elytra. According to Crowson (1981) the modified structure of the pterothorax in Coleoptera is associated with the development of the wings. The metathoracic wings generate all the flight forces necessary for lift and propulsion and the metathorax has consequently developed to accommodate larger muscles. Furthermore, the loss of the flight function in the elytra has lead to a corresponding reduction in mesothoracic size. Crowson (1981) also asserts that the requirements for stability in flight, particularly when the prothorax is large, has necessitated the anterior migration of the wing insertions, and contends that in some beetle groups this has developed to such an extent that the wing insertions may even be situated anterior of the mesocoxae. This in turn has lead to the metepisternum being almost horizontally positioned with the metapleural suture also running horizontally for most of its length.

The development described above applies particularly well to A. soleatum. The prothorax is large and the mesothorax is greatly reduced in comparison with the metathorax (Fig. 14). The mesopleural suture (Fig. 26, ps2) does not completely

divide the mesopleuron, whose orientation is dorso-ventral. In contrast, the metepisternum (Fig. 14, D; Fig. 26, es3) is almost horizontal in position and ventrad of the metepimeron (Fig. 26, ep3). The metepisternum is well sclerotised and bears setae (Fig. 14, D), whereas the metepimeron is membranous and protected by the elytron. A clearly discernable metapleural suture separates the two sclerites (Fig. 26, ps3).

In dorsal aspect the normal elements of the pterothorax are present. The mesonotum is greatly reduced and approximately V-shaped in outline. The mesoscutum (Fig. 27a, s) is sclerotised while the mesoprescutum (Fig. 27a, ps) is not. The prescutum is not easily detected as it is withdrawn beneath the posterior rim of the pronotum. The mesoscutellum (Fig. 27a, scm) takes the form of a raised projection which fits between the medial margins of the elytra. It is basally associated with a depression (Fig. 27a, d) in the centre of the scutum. The anterior wing processes (Fig. 27a, ap) are evidenced by slightly sclerotised, shallow convexities in the lateral margins of the scutum. The posterior wing processes (Fig. 27a, pp) are formed by lateral extensions of the scuta. The metanotum is membranous and relatively much larger than that of the mesothorax. The metaprescutum (Fig. 27b, ps) is large and broad. The metascutellum (Fig. 27b, scm) completely bisects the metascutum (Fig. 27b, s) which forms two separate, lateral sclerites. The metascutellum comprises a narrow medial region, bounded by grooves and extending over the metapostnotum, and two lateral regions enclosed by the scutum. The metapostnotum (Fig. 27b, pn) has a broadly triangular outline in dorsal aspect. The anterior and posterior wing processes (Fig. 27b, ap; pp) are formed by knob-like protrusions of the scuta.

In ventral aspect, the sterna of the meso- and metathorax are fused to form a pterosternum (Fig. 28, s 2+3), which together with the first visible abdominal

sternum, are sexually dimorphic. In the female (Fig. 28a), the pterosternum is broadest anteriorly, while in the male (Fig. 28b) it is broadest approximately midway between the anterior and posterior margins of the same. In addition the male is generally narrower than the female. The mesocoxae are separated by an intercoxal process (Fig. 28b, icp) which also results in the mesocoxal cavities (Fig. 28a, cc2) not being contiguous.

Legs: Wagner (1908) in his description of A. soleatum, states that the legs are short and oval ("Beine kurz und ziemlich plump"). In fact, the legs are relatively long in relation to the whole body. It is possible that Wagner was comparing the legs of A. soleatum with those of other apionids. The pro-, meso- and metalegs all possess generally the same structure, with the exception of the protibia, whose apexes are not as densely clothed in hairs as the others. Wagner (1908) also drew attention to this fact. The coxae are large and protrude from the ventral margin of the lateral silhouette. The metacoxae, however, while still large, do not to project to the same extent. In addition the coxae bear only a few setae. All the legs possess well defined trochanters which completely separate them from the femurs. The presence of a well developed trochanter is of taxonomic importance (Wagner 1909). Femurs are narrower apically and basally, and expanded centrally, with the profemur appearing to be the broadest of the three. They all bear many prostrate setae. The tibiae are long and slender but are slightly thicker apically. The tibia of the mesothoracic leg bears a downward projecting fixed spine at its apex. This tends to be covered in hairs which makes it difficult to see. Scattered prostrate setae supplement the apical hairs over the entire tibial surface. The tarsi comprise five distinct regions, there being some debate as to whether these regions constitute segments or not. The first two regions are approximately equal in size and shape and are undoubtably segments. The third region comprises two lateral lobes whose bases are confluent and adjacent the distal margin of the

second tarsal segment. Van Den Berg (1972) and Phelps (1956a) both assert that this is the third tarsal segment, however the fourth region, which is minute and situated between the lobes of the third, is regarded as a segment by Van Den Berg (1972) and as part of the third segment by Phelps (1956a). Phelps (1956a) considered the distal claw bearing region to represent the fusion of the fourth and fifth segments. On close examination, the tarsi of A. soleatum appear to be 4-jointed and therefore comprising five true tarsal segments. When viewed in dorsal aspect, the fourth segment can be seen to be attached at its base to the third segment and not to the second. The proximal three tarsal segments are all supplied with hairs, but the lobed third segment possesses on its ventral surface a dense hair pad. Wagner (1908) asserted that in the male the ventral surfaces of the tarsi were covered with a dense hair pad. Contrary to this assertion, both male and female specimens examined possessed hair pads, although only on the venters of the third segment. The fifth segment is elongate, slender and smooth, and bears apically two recurved divaricate claws. This feature is one of only a few which conform with the characteristics of the genus Apion (Kissinger 1968).

Wings: The elytra are similar in both sexes, variation only being exhibited in size. They are strongly convex in lateral aspect (Fig. 14). Each elytron bears nine distinct striae which coalesce near the posterior ventral margin. The striae take the form of deep grooves which possess a variable number of deeper pits into which single, anteriorly directed setae are inserted. According to Crowson (1981), the strial punctures of elytra differ from the setiferous punctures arising on the cuticle. Strial punctures never have setae arising from their centres, but may have setae arising from a pit in one side of the puncture. In many cases the strial punctures are floored with a clear membrane. This is the case in A. soleatum, whose elytra, when examined under high magnification, can be seen to possess a slit-like region in the pits, which clearly correspond to the clear membrane of

Crowson (1981). The interstrial spaces appear as ridges and bear a double row of narrow prostrate setae. On the basal costal margin of each elytron, a raised shoulder-like convexity is present. Wagner (1908) referred to these as "schulterbeulen" (humeral calli).

The metathoracic wings are large in comparison with the whole insect, measuring approximately 3 mm in length (Fig. 29). A. soleatum is a powerful flier although when disturbed, tends to fall to the ground where they are difficult to see. Wing venation is very reduced and the wing membrane possesses lightly sclerotised regions which probably strengthen the wing during flight. The upper surfaces bear minute spines which are only visible under high magnification.

4.4.5 The Abdomen

Five visible and heavily sclerotised sternites are present in both sexes of A. soleatum. However, the abdominal sternites posses features which are sexually dimorphic and which can be used to distinguish males from females.

Some disagreement with respect to the position of the morphologically first two sternites in rhynchophorous insects occurs. According to Sharp (1918) and Phelps (1956a), these sternites are modified to form a Y-shaped ventral phragma situated internally near the posterior margin of the metathorax. Morimoto (1962) asserts that the first two sternites form the posterior wall of the metacoxal cavity, an opinion followed by Van Den Berg (1972). In the case of A. soleatum both the Y-shaped structure and the characteristic double sclerited posterior walls of the metacoxal cavities are present.

The first two visible abdominal sternites (Fig. 28, 3; 4) are broad and immovably fused. The line of fusion is represented by a slightly impressed suture which does not bear any setae. The anterior margin of the first of these sternites is medially produced to form an intermetacoxal process (Fig. 28, imcp), the shape of which differs between the sexes. In the female (Fig. 28a) this projection is broadly convex apically, while in the male it forms a distinct point. The posterior intercoxal margin of the metathorax is recessed to receive this projection. The third and fourth visible sternites (Fig. 28, 5; 6) are located slightly dorsad of the second and well developed membranes are visible between sternite two through five. In addition, the third and fourth sternites together are approximately as broad as either one of the preceding anterior sternites, a feature which confirms A. soleatum's placement in the Apionidae. The ventral outline of the fifth sternite differs between sexes. As found in P. varium (Phelps 1956a), the posterior margin of this sternite in females is convex and the general shape is triangular, whereas in the male the posterior margin is slightly concave and the general shape, trapezoidal (Fig. 28a & b). Visible sternites 1, 2 and 5 are well supplied with setae while sterna 3 and 4 tend to possess setae only near their lateral margins.

There are seven visible, membranous tergites which are all hidden by the elytra. Owing to their membranous nature they are difficult to discern but are all of roughly the same shape with the exception of the first visible tergite. The anterior margin of this tergite is concave and fits around the posterior margin of the metapostnotum.

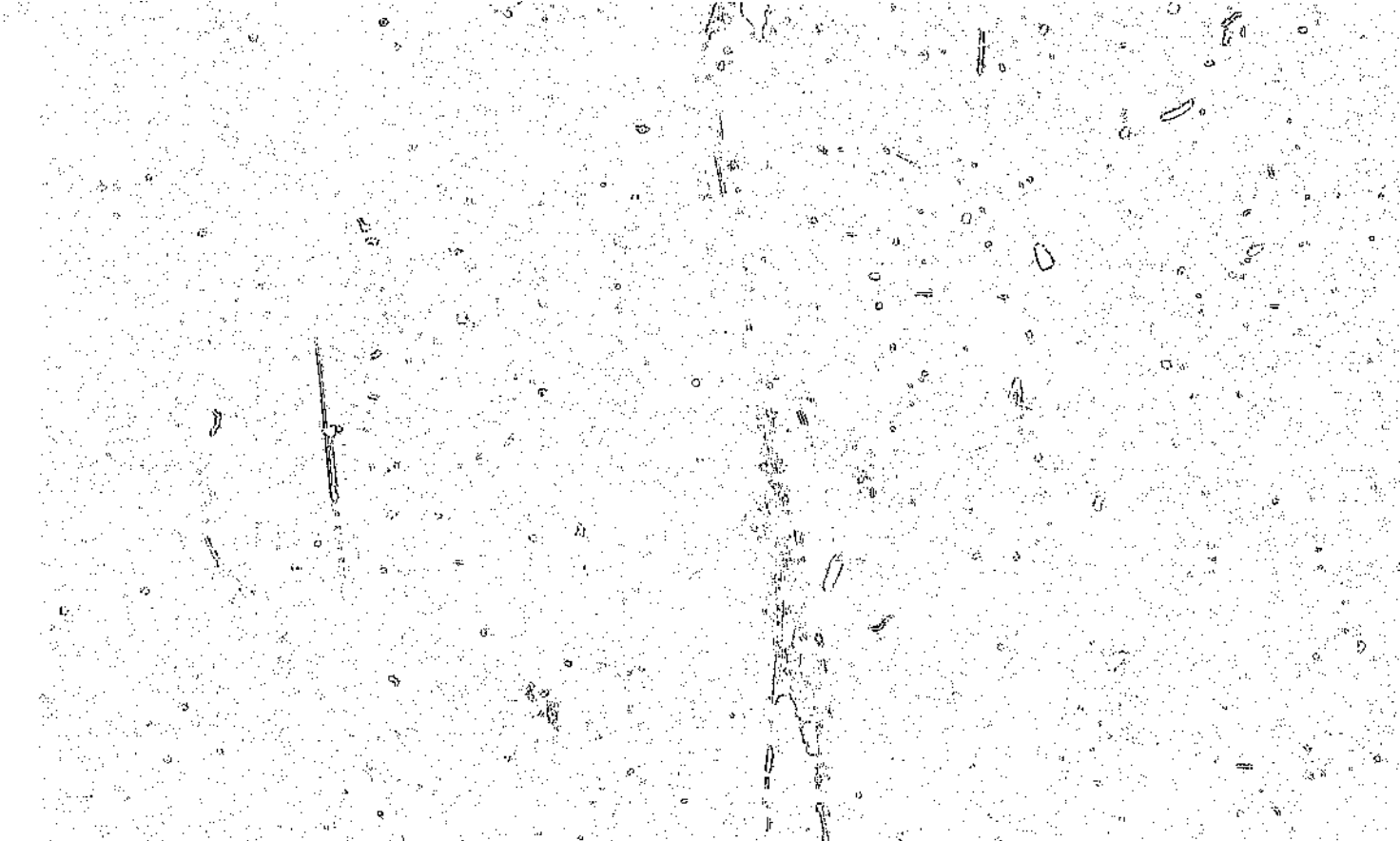


Fig. 14. Lateral aspect of adult of A. soleatum

A post-ocular constriction, B metathoracic pit, C pterosternum, D metepisternum, a antenna, c compound eye, cos circumorbital suture, mc metacoxa, me.pl mesopleuron, mf metafemur, mt metatrochanter, mtar metatarsus, mtb metatibia, pn pronotum, po.l post ocular lobe, r rostrum, sc scrobe, str striation, st1 first visible abdominal sternite, st2 second visible abdominal sternite, t tarophi.

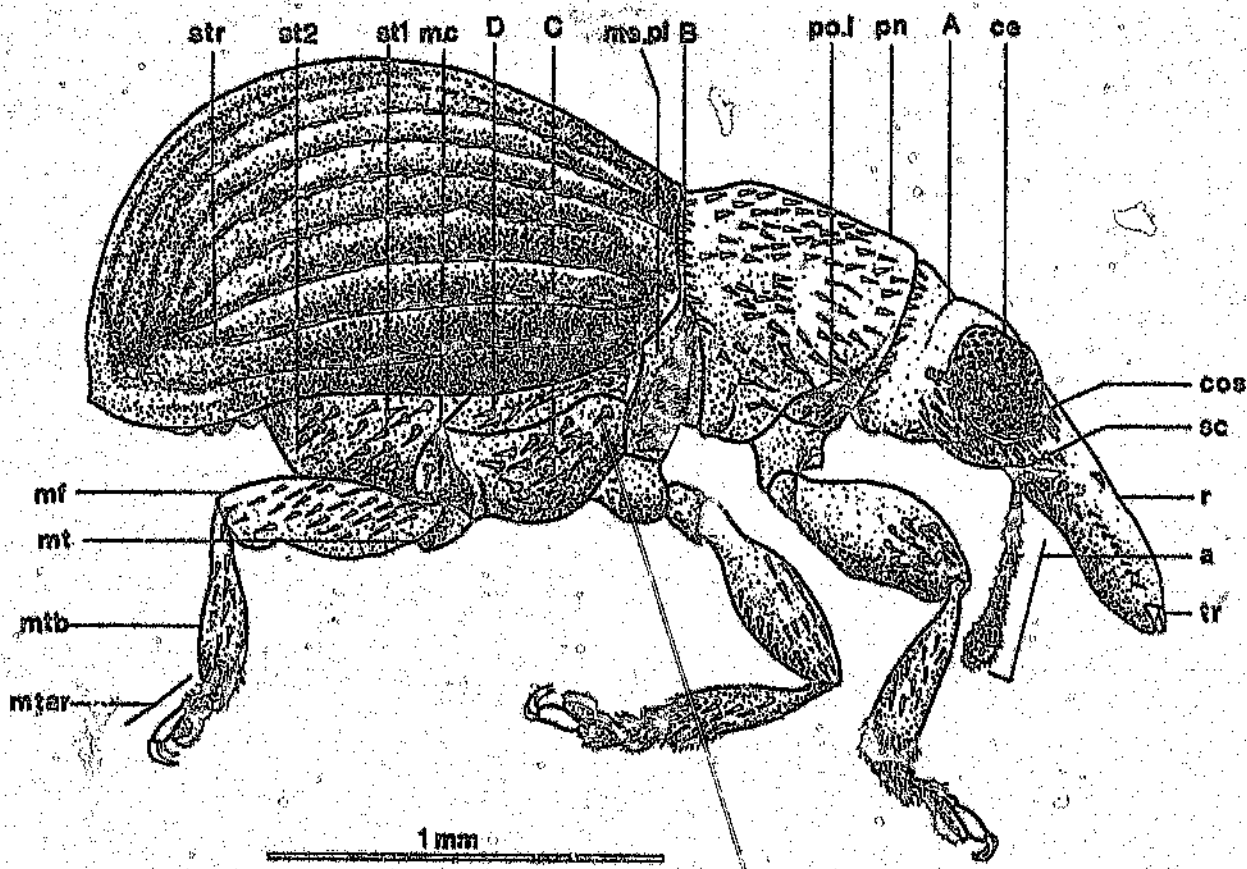


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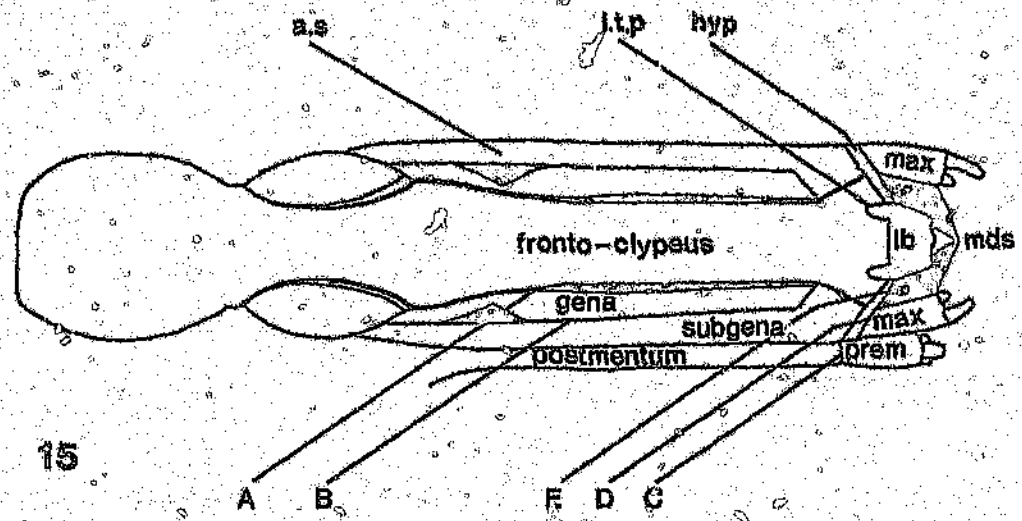
Fig. 15. Rolled out schematic diagram of dorsal aspect head of adult A. soleatum (legend as for Fig. 16)

Fig. 16. Rolled out schematic diagram of ventral aspect of head of adult A. soleatum

A genal suture, B subgenal suture, C labial suture, D hypostomal suture, E pleurostomal suture, F postoccipital suture, as antennal socket, ce compound eye, hyp hypostoma, lb labrum, l.t.p lateral tormal process, max maxilla, mds mandibles, p.o postocciput, prem prementum, p.tca posterior tentorial pit.

Fig. 17. Ventral aspect of rostrum of adult A. soleatum

ce compound eye, g gena, hyp hypostoma, mx.art maxillary articulation, pg postgena, po postmentum, preart preartis, sc sorobe, sgn subgena.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hyp
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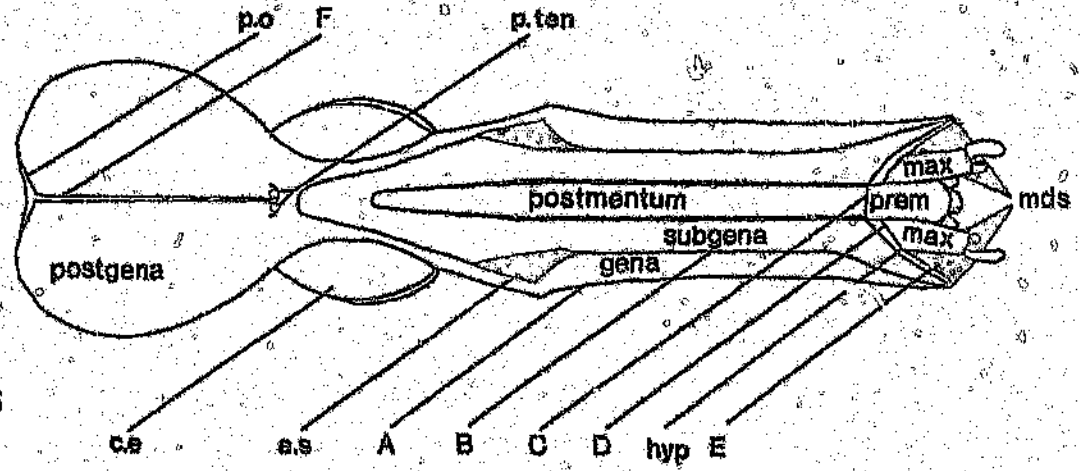
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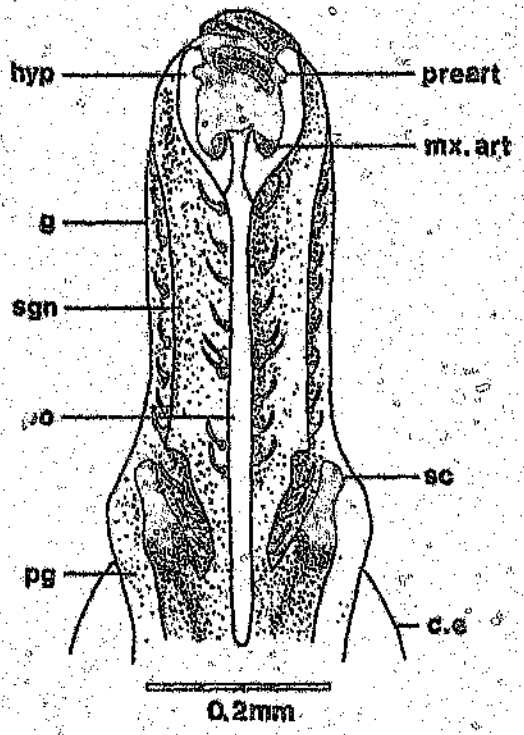
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Fig. 18. Dorsal aspect of labrum of adult A. soleatum

f-c fronto-clypeus, l.set labral setae,

Fig. 19. Ventral aspect of labrum and epipharynx of adult A. soleatum

cl clypeus, lf lateral files, l.t.p lateral tormal process, m.pc mandibular postcoila.

Fig. 20. Ventero-lateral aspect of right mandible of adult A. soleatum

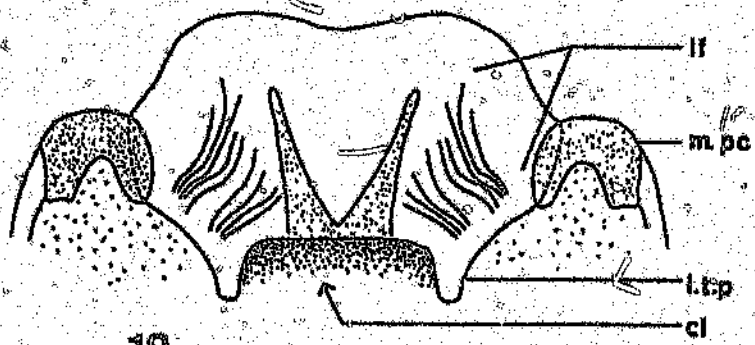
a acetabulum, ab.m mandibular abductor muscle, ad.m mandibular adductor muscle, c condyle, dt distal tooth, mt median tooth, ph.br pharyngeal bracon, preart preartis, pt proximal tooth.

Fig. 21. Dorso-lateral aspect of right mandible of adult A. soleatum

ab.m mandibular abductor muscle, ad.m mandibular adductor muscle, md.set mandibular seta, ph.br pharyngeal bracon, poart postartis.

Fig. 22. Mesal aspect of right maxilla of adult A. soleatum

ca cardo, lac lacinia, lac.t lacinial teeth, ml.s malar setae, mx.con maxillary conical papillae, mx.plp maxillary palpus, pf palpifer, sg subgalea, st stipes, st.set stipital seta.



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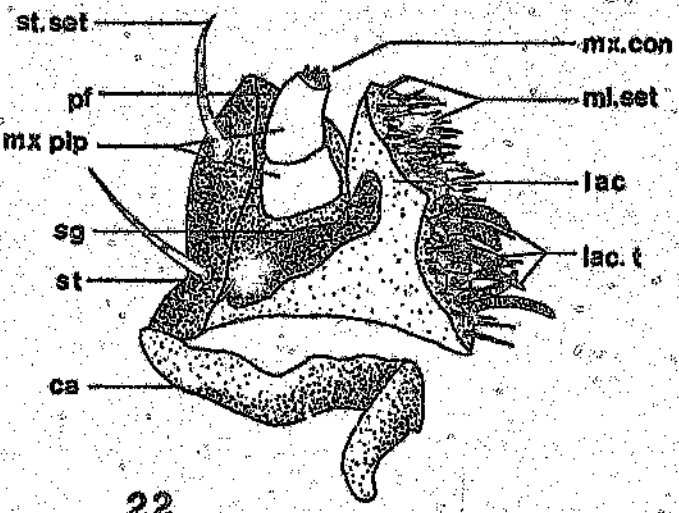

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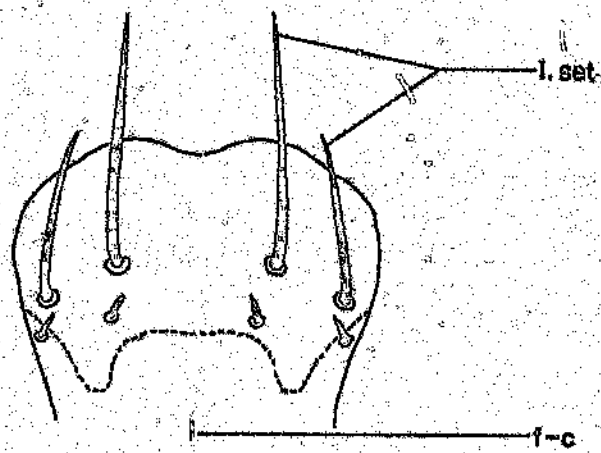

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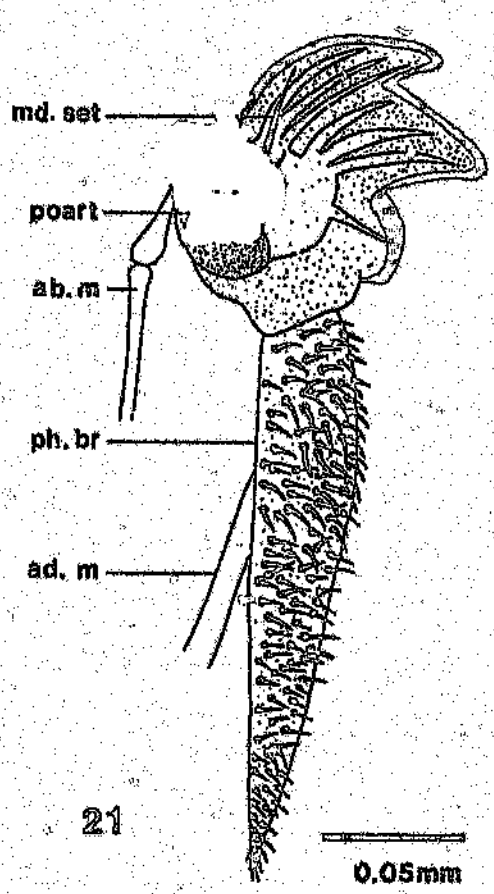

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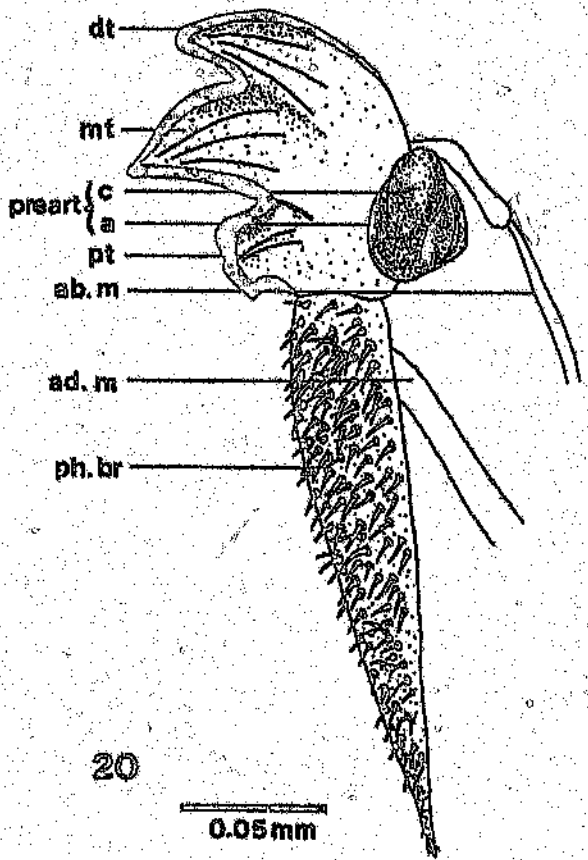

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Fig. 23. Ventral aspect of prementum of adult A. soleatum

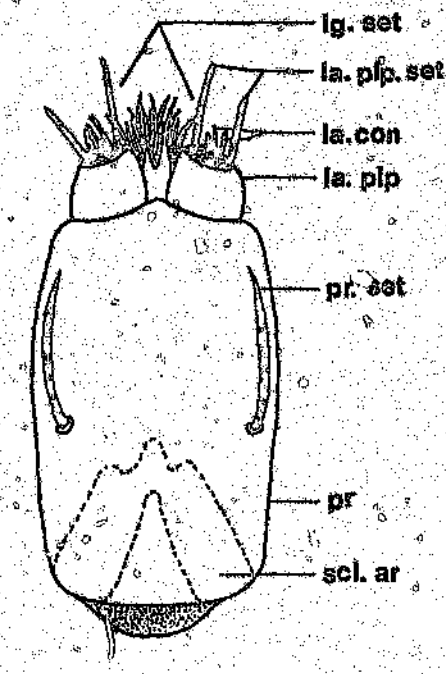
la.con labial conical papillae, la.plp labial palpi, la.plp.set labial palpal setae, lg.set ligular setae, pr prementum, pr.set premental seta, scl.ar sclerotised arch.

Fig. 24. Lateral aspect of prementum of adult A. soleatum

la.plp labial palpus, lg ligula, lg.set ligular setae, pr prementum, pr.set premental seta, scl.ar sclerotised arch.

Fig. 25. Antenna of adult A. soleatum

scp scape, p pedicel, f flagellum.



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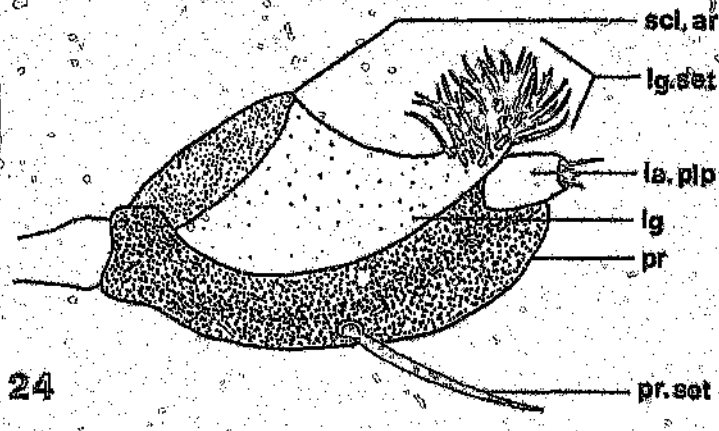

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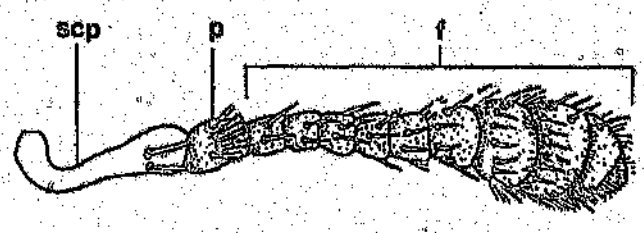

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Fig. 26. Lateral aspect of pterothorax of adult A. soleatum

c2 mesocoxa, ep2 mesepimeron, ep3 metepimeron, es2 mesepisternum, es3 metepisternum, ps2 mesopleural suture, ps3 metapleural suture, s2+3 pterosternum.

Fig. 27a. Dorsal aspect of mesonotum of adult A. soleatum

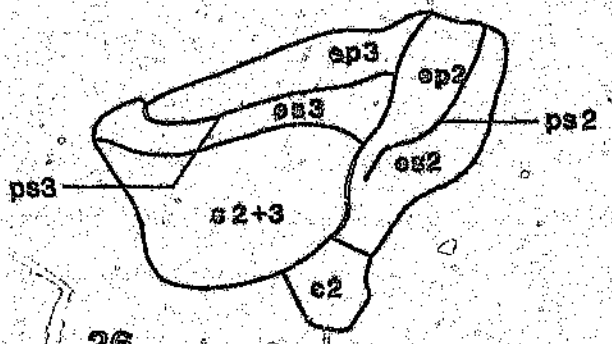
Fig. 27b. Dorsal aspect of metanotum of adult A. soleatum

ap anterior wing process, d depression, pn metapostnotum, pp posterior wing process, ps prescutum, s scutum, scm scutellum.

Fig. 28. Ventral aspect of pterothorax and abdomen of adult A. soleatum
a. female. b. male

c2 mesocoxa, cc2 mesocoxal cavity, icp intercoxal process, imcp intermetacoxal process, s2+3 pterosternum, 3-7 first five visible abdominal sternites

Fig. 29. Dorsal aspect of left metathoracic wing of adult A. soleatum



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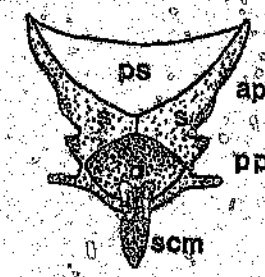

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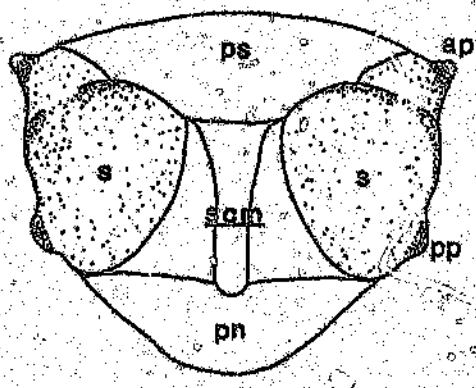

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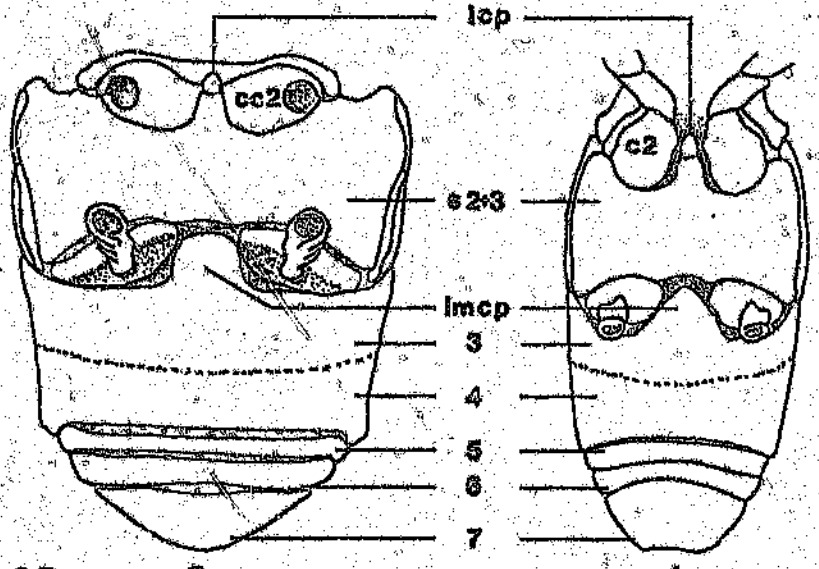

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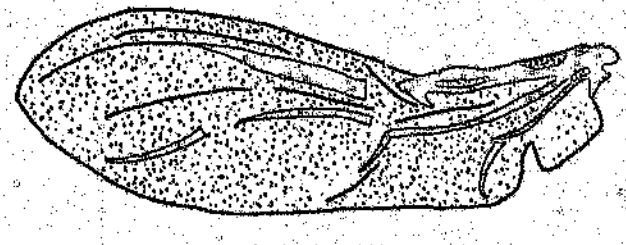

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4.5 Summary

Although this species is clearly a member of the Apionidae (sensu Crowson and others) or the Apioninae (sensu Kissinger), it does not conform with the characteristics of the genus Apion Herbst. The adult head is constricted at the base behind the posterior margin of the eye, the anterior margin of the prothorax does not lack an obvious post-ocular lobe, the mesothorax does not lack a deep lateral pit near the posterior margin of the prothorax, and the body does not lack numerous, stout, club-like setae. According to Alonzo-Zarazaga (1988 pers. comm.) the genus Apion is considered to be palaearctic, and that this particular species should be redescribed in another genus. The morphological work presented above should facilitate the redescription of A. soleatum with ease.

The larva is fleshy, creamy white and crescentic in form. The segments of the thorax and abdomen are clearly discernable. The division of the terga by a transverse fold is characteristic.

While the terminology used for the description of immature Coleoptera is relatively uniform, spiracular terminology is confusing. In an attempt to standardise the terminology associated with spiracles, the suggestion that the terms annular, biforous, bifid and cribiform be used to describe the form of the atrial orifice was made, while the terms acameral, unicameral and bicameral etc. be used to denote the presence or absence or number of lateral air tubes.

The pupa of A. soleatum varies in length and exhibits varying degrees of sclerotisation. It differs from the pupae of P. varium and A. ulicis in that the rostrum does not attain the abdomen, and the metalegs are ventrad of the wings. Thoracic segments are difficult to discern and ten abdominal segments are present.

CHAPTER 5. THE LIFE CYCLE OF A. soleatum ON COTTON

5.1 Introduction and aims

The life table is a summary statement on the life of an individual of a population (Price 1970) and is considered to be the best way of quantifying the life history and survivorship of individuals of a species. The construction of life tables for A. soleatum was considered, but several factors suggested that this was not presently feasible. Firstly, according to Price (1975), the detailed life cycle of the insect in question must be known, so that all stages can be readily found. Good life cycle data also enable the accurate timing of sampling for the different stadia. The recent exploitation of cotton in South Africa has meant that no work has been done on this insect, and that nothing is known of its life cycle. Another factor which makes the construction of life tables difficult is the identification of agents of mortality (Harcourt 1969). The quantification of predator effects is problematic since predators often remove the entire prey. The construction of life tables for A. soleatum is not feasible given the scope of the study. However, a preliminary contribution in terms of the natural history of A. soleatum on cotton can be made within the scope of this investigation. The aims were thus to make a qualitative description of the life cycle and activities of A. soleatum, to determine the number of larval instars, to determine whether any natural enemies of A. soleatum exist and to see if any natural host plants exist in areas where A. soleatum is distributed.

The technique of measuring head capsule widths in order to determine the number of larval instars has been used by various workers eg. Phelps (1956b), Wade

(1961), Leibee et al. (1980), Hopkins & Whittaker (1980a) and Beaver & Sanderson (1989). Daly (1985) reviews the subject of insect morphometrics. Growth of unsclerotised body parts may appear to be continuous, with discontinuities only being evident in the sclerotised parts, such as the head capsule. When these are measured they tend to show constant proportional increments (Hinton and Mackerras 1970). This constancy of increase was first noted by Dyar (1890), and since then has become known as Dyar's law. According to Crowson (1981), two factors affect the number of larval instars of a species. The first is the ratio of the size of the egg to the adult, and the second is the degree of sclerotisation of the larval integument. The greater the degree of sclerotisation, the less the amount of growth that can be accommodated in an instar. A. soleatum larvae are fleshy and not heavily sclerotised, thus one would expect only a few larval instars. According to Beaver and Sanderson (1989), the technique of plotting a frequency distribution of head capsule widths is suitable if little or no overlap in the measurements from different instars exist. They stated further that under these conditions the head capsule width measurement of any individual could be used to determine its instar.

5.2 Methods

An account of the life cycle of A. soleatum was developed from observations made during visits to cotton growing areas where the insect was present. Photographs of the results of various of the activities of A. soleatum were taken to support statements.

With respect to the number of larval instars, the method of measuring the width of larval head capsules was employed. The head capsules of 125 field collected A. soleatum larvae were measured with the aid of a drawing tube fitted to a stereo microscope and a Zeiss calibration slide. Head capsules were drawn onto paper

at a fixed magnification. The calibration slide was also drawn onto the paper at the same magnification. Measurements of the drawn head capsule widths were made with a ruler and assigned to scaled classes varying from 3.5 mm to 13.49 mm with increments of 0.49 mm. The frequency distribution was then plotted and the scale class intervals converted to real class intervals by forming a quotient between the scaled class intervals and the scale length of one millimetre.

To determine whether any natural insect enemies of A. soleatum occurred, the presence of other insects which were observed to be closely associated with A. soleatum was noted during surveys of cotton production areas, and also at Malelane, where trials were conducted (Chapter 6). Larvae of A. soleatum were immersed in boiling ten percent NaOH to make larval parasitoids visible (Bennett and Nel, 1990).

In order to establish whether there were any indigenous host plant species for A. soleatum, surveys of natural bush adjacent to cotton fields in which A. soleatum had been recovered were undertaken. In most cases, this natural vegetation extended along the length of the cotton field. The surveys involved entering the bush, following a zig-zag path with legs of approximately 25 meters and examining plants which exhibited typical A. soleatum leaf damage (i.e. leaves with shot-holed appearance). These plants were then subjected to a more careful investigation, which included the stems being split for larval and pupal tunnels. Surveys were also undertaken in natural vegetation adjacent to fields in which cotton had previously (i.e. one or two seasons before) been planted. This was done in order to take into account the possible preference of A. soleatum for cotton, which would result in them avoiding natural host species. Such surveys were conducted in the same way as described above.

5.3 Results and Discussion

5.3.1 Life cycle

The eggs of A. soleatum were never found, although young larvae were easily recovered from oviposition sites which were generally located near the axils of lateral branches. Oviposition sites on young cotton plants were made visible by the presence of a small, circular discolouration on the stem. At its centre a lighter coloured circular region, probably corresponding to the actual oviposition, was common (Fig. 30). This form of oviposition appears to be common amongst other members of the genus eg. A. dichroum Bedel (Freeman 1967), A. melanarium Gerst., A. longirostre Oliver (Tuttle 1954), A. chirindanum Wagner (Phelps 1956b) and A. ulicis (Maldwyn Davies 1928). In young cotton, single A. soleatum larvae were found under such stem discolourations, but on older, ratoon cotton, several could be observed under the bark in the vicinity of a single axil. The above mentioned authors all noted that females made an oviposition hole with their mouthparts, into which a single egg was deposited. In some cases the hole was again filled with plant tissue by the female. Although oviposition was not observed in A. soleatum, the similarities in oviposition site structures between this species and other Apion spp., suggests that the same probably occurs in A. soleatum as well.

On hatching, the larvae feed on both phloem and xylem tissues (secondary xylem in older plants - Chapter 7) while tunnelling either up or down the stem. Although no data were collected to indicate whether there was a preference for tunnelling up or down in A. soleatum, Hopkins and Whittaker (1980b) found no directional preference for A. violaceum Kirby on a Rumex host. The frass deposited as a result of larval feeding, leaves a characteristic red-brown stain in

the stem (Figs 31, 32). The discolouration of secondary xylem vessels was also observed on closer examination of the stem (Chapter 7). The red-brown frass serves as a useful indicator of the presence of A. soleatum in field cotton, and is easily detected when cotton stems are split open. Pupation occurs in the larval tunnels, often just under the bark (Fig. 33). On several occasions a small "plug" of bark tissue was observed, which suggested that the final instar larva probably cuts an exit hole to facilitate the emergence of the adult. This phenomenon was only ever observed on older cotton, whereas on younger, first season cotton, adults were occasionally observed moving up or down within a larval tunnel. No plug was observed anywhere along the length of the tunnel.

Emerging adults move to the leaves, especially near the apex of the plant, where they feed and mate. Feeding involves the removal and consumption of small circles of leaf tissue, and results in circular holes measuring some 1.009 mm ± 0.26 (mean ± SE mean, n=30) in the leaf surface. The holes are of varying depth and may even extend right through the leaf. Adult feeding eventually results in a typical "shot-hole" appearance of the leaves, a feature also noted by Tuttle (1954) in several Apion spp. The shot-hole appearance of the leaves is easily detected when walking through a field of cotton which together with the red-brown frass staining of the stems, is confirmation of the presence of A. soleatum.

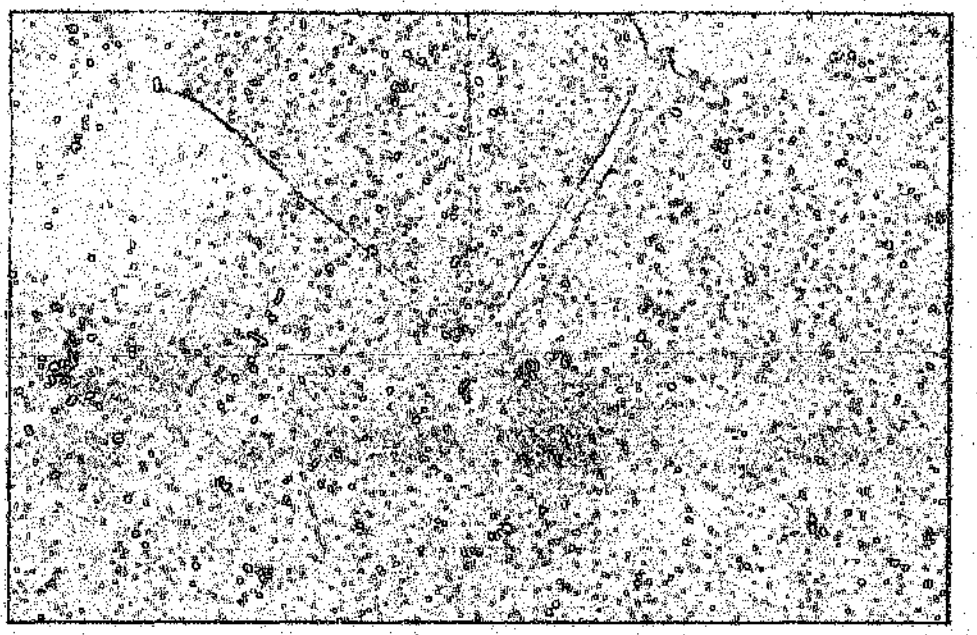


Fig. 30 Oviposition site on young cotton

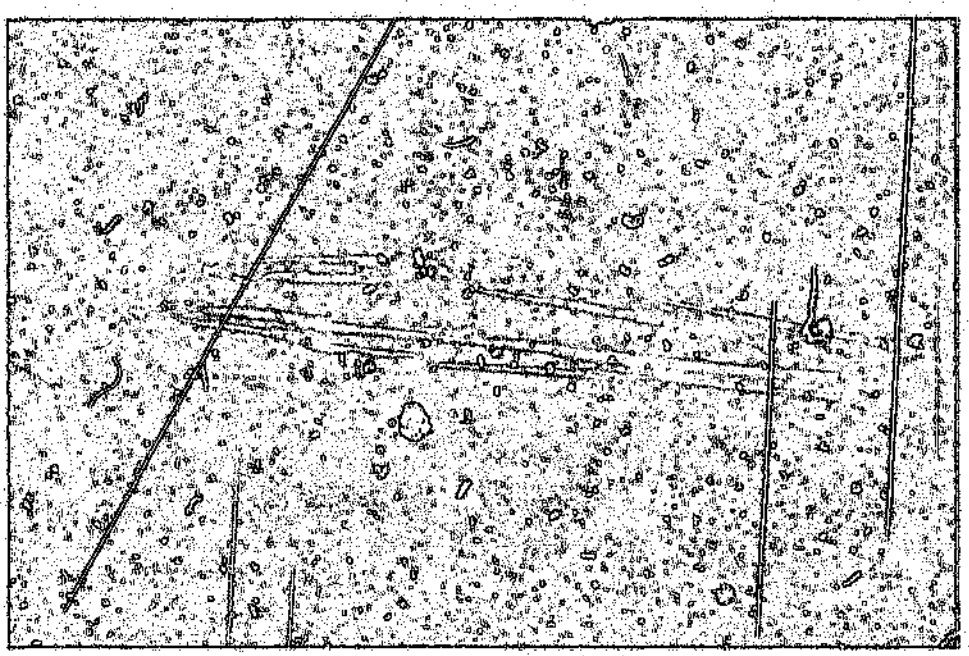


Fig. 31 Larval damage in main stem

Fig. 32 Larval frass in tunnel

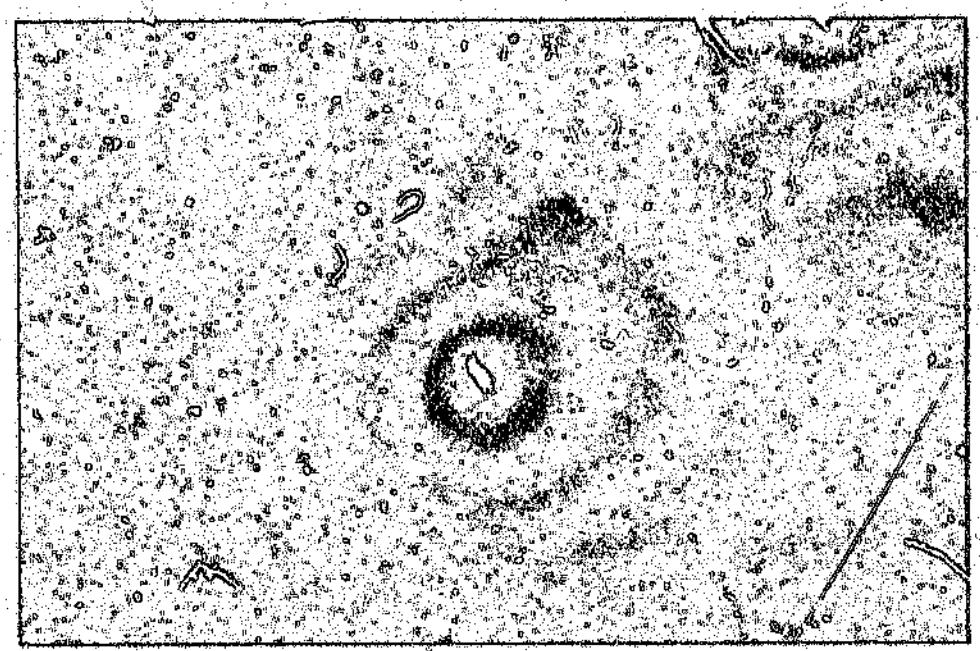


Fig. 33 Pupa in stem

Mating behaviour was observed in holding containers (described in Chapter 6) and under field conditions. Males and females approach each other from the front whereupon some form of acceptance/rejection is mediated. On many occasions males turn and move away from a female, and then mate with a different one, behaviour which may indicate that the female was not a virgin. According to Maldwyn Davies (1928) the spermatheca of virgin females of A. ulicis were found to be full after a single copulation. If the male and female accept each other, the male mounts the female, the aedeagus is inserted and copulation takes place. During copulation the female may move around without copulation being disrupted.

During field cage trials to determine the effect of A. soleatum on cotton yield and quality, cages infested with adult A. soleatum were visited on an average of every three weeks. The adults with which the initial infestations were made could not be located during the subsequent visit, save a few dead individuals at the bottom of the cages. On the third visit, approximately nine weeks after the initial infestation, live adults were again found in the cages. This suggests that the duration of the life cycle from oviposition to adult emergence is probably between 50 and 70 days in summer. Observations made in ratoon cotton in the winter months in the Mkuze and Malelane areas, indicated that all stages are capable of overwintering, although winter temperatures in this area are not extremely cold (Table 5).

Table 5. Maximum and minimum temperatures (°C) recorded at Makatini over the winter months. (Data extracted from Monthly Weather Reports published by the Weather Bureau, '*' indicates data not recorded.)

YEAR	MAY		JUNE		JULY		AUGUST	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1985	26.0	12.5	25.2	9.8	25.2	9.5	27.7	11.2
1986	28.9	13.0	26.0	9.5	26.5	8.6	29.1	12.5
1987	29.6	14.1	25.1	8.5	24.8	9.8	25.5	11.3
1988	28.2	12.1	24.2	8.4	*	*	*	*
1989	27.3	13.5	24.3	10.7	24.9	9.1	28.8	13.8
MEAN	28.0	13.0	25.0	9.4	25.4	9.3	27.8	12.2

5.3.2 The number of larval instars

The frequency distribution of larval head capsule widths is presented in Fig. 34 Three clear and almost discontinuous ranges of widths occur, and it is concluded that three larval instars are present. The same was found for Ceratapion basicorne (Illiger) (Clement et. al 1989), A. curtirostre (Hopkins and Whittaker 1980a), A. dichroum (Freeman 1967) and Cylas species (Chalfant et. al 1990).

5.3.3 Natural enemies of A. soleatum

The only recorded enemy of A. soleatum is a parasitoid wasp, Entedon apionidis Ferrière, a member of the Eulophidae (Hymenoptera: Chalcidoidea) which was first described from Tanzania (Ferrière 1938). Evidence exists to suggest that the adult wasp lays a single egg in an A. soleatum larva (Bennett and Nel 1990) (Fig. 35). The larval wasp then develops at the expense of the apionid and finally

pupates within the stem adjacent to or in the disintegrating apionid (Bennett and Nel 1990). E. apionidis and A. soleatum are invariably found at high population densities in ratooned cotton. The presence of E. apionidis was first noted in South Africa in October 1988 (Bennett and Nel 1990). It is arguable that the initially high A. soleatum populations, which caused alarm in 1984 and 1985, and which since then have not been considered as cause for concern, may have been reduced by the build up of this natural enemy. Control strategies, should they become necessary, must take the presence of E. apionidis into consideration (refer to page 99).

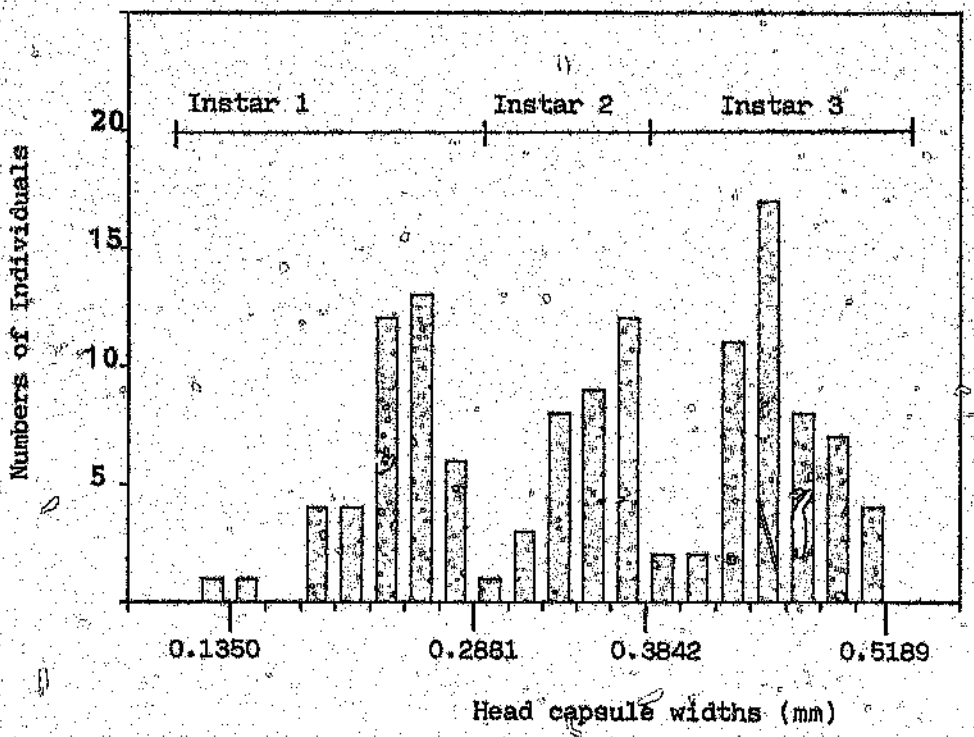


Fig. 34 Frequency distribution of larval head capsule widths

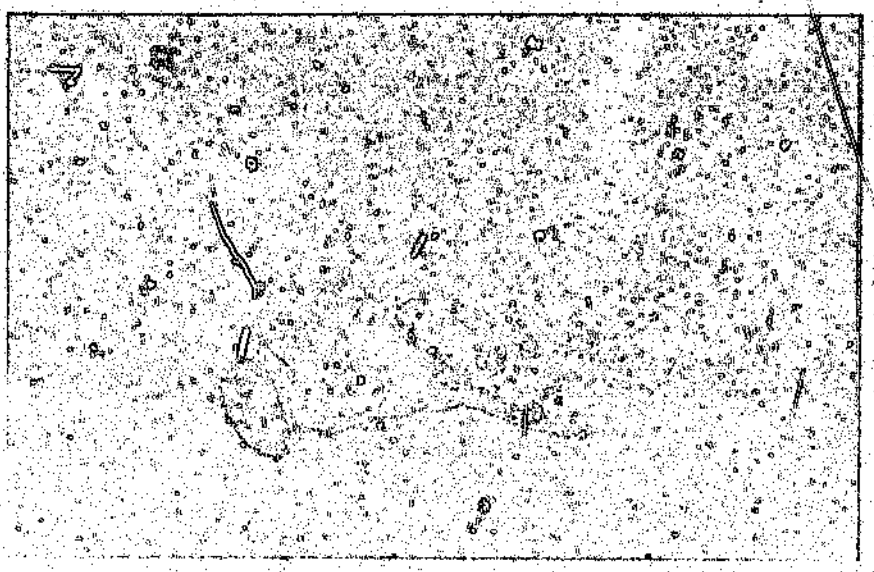


Fig. 35 Larva of E. apionidis within larva of A. soleatum

5.3.4 Natural host plants of A. soleatum

Since the species of cultivated cotton belong to the family Malvaceae, and bearing in mind that A. soleatum appears to be well adapted to cotton, it was felt that a natural host of A. soleatum would probably be a member of this family. According to Moll (1981), Ross (1972) and Coates Palgrave (1977), Malvaceae is represented by 14 genera comprising 56 species in South Africa. Most of these species occur in Northern Natal (Zululand) and the Eastern Transvaal, regions where A. soleatum is distributed. The wild cotton, Gossypium herbaceum race africanum, as well as Gossypioides kirkii are among these 56 species and were found during the surveys of natural vegetation in the Malelane and Pongola/Mkuze areas. None of the surveys yielded any A. soleatum. In addition, cotton scouts of Mjindi Estates in the Makatini were asked to search bush for A. soleatum, yet this too did not yield any results (Groenewald 1990, pers. comm.) Pearson (1958) cited an unpublished report of Harris (1942) in which experimentally grown Gossypioides kirkii was "slightly attacked" by A. soleatum. It is clear that cultivated cotton has become the major, if not only, host of A. soleatum.

CHAPTER 6. THE EFFECT OF Apion soleatum INFESTATIONS ON THE GROWTH, YIELD AND QUALITY OF COTTON

6.1 Aims and methods

The aim of this part of the study was to determine the effect of A. soleatum on the cotton plant. This was especially important since quantitative studies of the effects of A. soleatum on growth, yield and quality were non-existent. Valid justification of pest status for A. soleatum was necessary before an assessment of the threat posed by this insect to the cotton industry, could be made.

Under the provisions of the Agricultural Pests Act of 1983, new measures, which prohibited the ratooning of cotton in certain areas, became effective on 12 September 1986 (Greeff and Niles 1987). In terms of this Act, all cotton plants and other host plants of A. soleatum within 100 m of a cotton field, were to be removed and burned not later than 1 August in Natal and the magisterial districts of White River, Barberton and Nelspruit. The planting of cotton and host plants of A. soleatum in these areas was also prohibited for the period 1 August to 30 September. Despite the obvious inadequacies of this promulgation (eg. hosts plants of A. soleatum have not been identified), it was necessary to obtain special permission in order to permit the ratooning of cotton on the Hoechst Experimental Farm near Malelane. This was done to ensure a constant supply of A. soleatum during the trial period.

In order to be able to artificially determine the level of infestation, field cages which could be placed over one or two plants were designed and made. The cages

measured approximately 1.0 m x 1.0 m x 1.8 m and possessed a sealable entrance of 0.5 m diameter in one side wall (Fig. 36). Deltapine Acala 90 was planted in a 0.8 ha field and grown under commercial conditions. Once the cotton seeds had been planted, 32 cages were erected in eight groups of four along a single row on the edge of the field. Despite the hazards of edge effects, the edge row was chosen to facilitate easy entrance to the cages. The small field size also tended to minimise these effects. Two field trials, one during the 1988/89 season and one during the 1989/90 season were carried out.

A. soleatum adults were collected with an aspirator from ratoon cotton for infestation purposes. They were then taken to the laboratory and placed in several plastic containers and allowed to settle in order to minimise the risk of selecting unhealthy or abnormal individuals. Adults were sexed by selecting copulating pairs from the holding containers. During the evening, the pairs were retrieved and placed in separate containers, each container being set aside for the infestation of a specific field cage. Equal numbers of males and females were chosen for each cage. Where the infestation level was uneven, one more female than male was chosen in order to maximise oviposition on the plant. At the end of each season measurements of various indicators of plant growth and yield were made. In the second season lint samples were sent to the Cotton Board for analysis.

6.1.1 The 1988/89 Trial

In the 1988/89 trial the effect of plant age at infestation was also investigated. At a plant age of five weeks after seedling emergence (ase.) cages were infested with A. soleatum adults at the following levels: 0 (control), 5, 8 and 12; with each treatment being replicated four times to give a total of 16 cages. The other 16

cages were infested at the same levels at a plant age of 12 weeks ase. Each cage contained one cotton plant. At the end of the season, measurements were made of plant height, plant mass, number of bolls produced, number of lateral branches produced and the number of leaves. These means were then statistically compared using the Bonferroni t-test (Dunn 1959, 1961; Bailey 1977) after a factorial analysis of variance had been performed on the data. Bonferroni's t-test was used in preference to the Least Significant Difference (LSD) test of Fisher (1935) because it was stricter. Steel and Torrie (1980) point out that the LSD test is often abused and state that in extreme cases where the experimenter compares only the difference between the highest and lowest treatment means, the differences will be substantial even when no effect is present. They add further that it can be shown that with three treatments, the observed value of t will exceed the tabulated level of t about 13 percent of the time, with six treatments the figure is 40 percent, with 10 treatments about 60 percent and with 20 treatments about 90 percent.

6.1.2 The 1989/90 Trial

Owing to the management of the experimental farm deciding to remove the ratooned cotton, the density of the A. soleatum population in the area fell to zero (Table 1). As a result A. soleatum adults were collected in the Makatini and transported to Malelane, so that the trial could proceed. These adults were allowed to settle for 72 hours before being placed in the cages. Cages were infested at levels of 0, 2, 8, and 12 A. soleatum adults. All the cages were infested at the plant age of eight weeks ase. Seventeen weeks ase. the numbers of bolls produced on each plant was recorded and at the end of the season measurements were made of, plant height, plant mass, the number of lateral branches produced and the mass of the seed cotton harvested. Means were statistically compared

using the Bonferroni t-test after an analysis of variance had been performed on the data.

6.2 Results

6.2.1 The 1988/89 Trial

The means of plant height, plant mass, number of lateral branches and number of bolls produced are presented in Table 6, together with the Bonferroni Least Significant Differences for the main effect, infestation level. The analyses of variance are given in Appendix C. Early infestation of cotton plants by A. soleatum generally tended to have a greater effect on plant growth than did the later infestation. Infestation level significantly influenced all the indicators of plant growth measured, in that all infested plants differed from the controls (Fig. 37). In general, the higher the infestation level, the lower the performance of the plant.

Table 6. Effect of level and time of Apion soleatum infestations on various cotton plant growth indicators: 1988/89.

a. Plant height (cm)

INFESTATION LEVEL	TIME OF INFESTATION		MAIN EFFECT: LEVELS
	EARLY	LATE	MEAN
0	98.50	98.50	98.50
5	67.75	65.00	66.38a
8	52.00	43.75	47.88a
12	43.75	70.00	56.88a
MAIN EFFECT: TIME	65.50	69.31	

LSD Bonf. (p = 0.05) for main effect level: 27.67
a Means not significantly different for main effect level.

Table 6. Effect of level and time of Apion soleatum infestations on various cotton plant growth indicators: 1988/89.

b. Plant mass (grams)

INFESTATION LEVEL	TIME OF INFESTATION		MAIN EFFECT: LEVELS
	EARLY	LATE	MEAN
0	500.01	500.01	500.01
5	147.84	233.43	190.64a
8	157.37	133.61	145.49a
12	49.14	235.00	142.07a
MAIN EFFECT: TIME	213.59	244.55	

LSD Bonf. (p = 0.05) for main effect: level: 303.61
a Means not significantly different for main effect: level.

c. Lateral branches (number)

INFESTATION LEVEL	TIME OF INFESTATION		MAIN EFFECT: LEVELS
	EARLY	LATE	MEAN
0	3.25	8.25	8.25
5	3.75	5.50	4.63a
8	3.25	1.50	2.38a
12	1.75	6.50	4.13a
MAIN EFFECT: TIME	4.25	5.44	

LSD Bonf. (p = 0.05) for main effect: level: 3.01
a Means not significantly different for main effect: level.

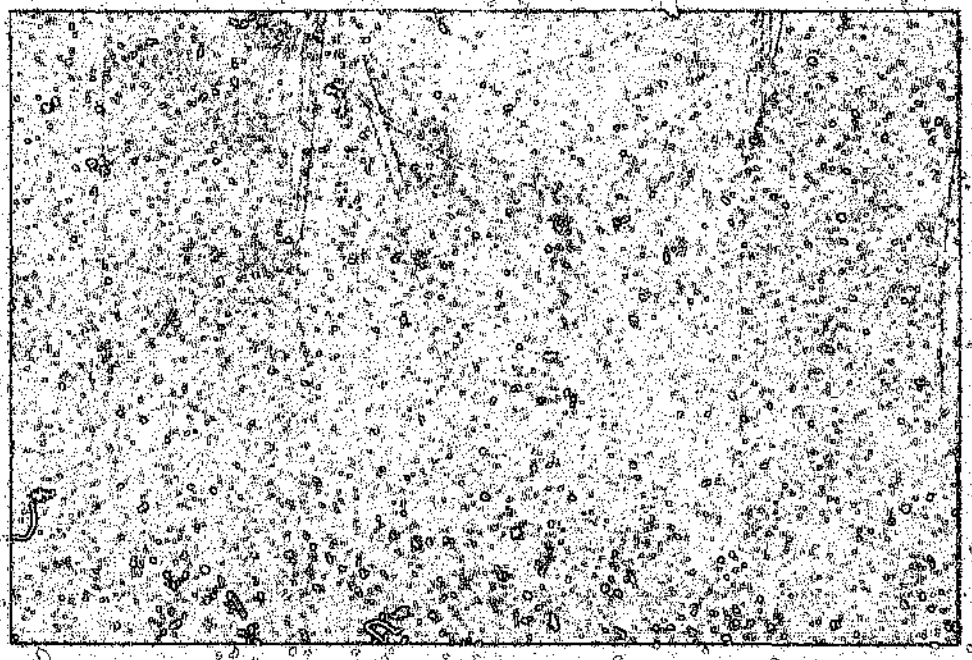
d. Bolls (number produced/plant)

INFESTATION LEVEL	TIME OF INFESTATION		MAIN EFFECT: LEVELS
	EARLY	LATE	MEAN
0	7.88	7.88	7.88
5	2.00	2.75	2.38a
8	0.76	1.50	1.13a
12	0.75	2.25	1.50a
MAIN EFFECT: TIME	2.84	3.60	

LSD Bonf. (p = 0.05) for main effect: level: 5.21
a Means not significantly different for main effect: level.

Fig. 36 Field cages used in trials at Malelane: 1988/89

a. Zero A. soleatum per plant



b. Twelve A. soleatum per plant

Fig. 37 The effect of two A. soleatum infestation levels on cotton plants: 1988/89

6.2.2 The 1989/90 Trial

The means of plant height, plant mass, number of bolls produced and the mass of seed cotton produced are presented in Table 7. The analyses of variance are given in Appendix C. Plant mass and the number of bolls produced were not significantly ($p>0.05$) influenced by infestation level. In general however, plants tended to perform less well the higher the infestation level. In the case of plant height and mass of seed cotton produced, infestation was significant according to the analysis of variance, but the Bonferroni LSD was too large to separate the infestation levels.

Fibre length, tenacity, elongation and micronaire are indicators of fibre quality used by breeders at the Tobacco and Cotton Research Institute in Rustenburg to assess the quality of lint produced by cotton breeding lines and cultivars. These were measured by the Cotton Board and are presented for each of the treatments in Table 8, together with the acceptable limits to which new cotton breeding lines are selected and bred (De Villiers 1991, pers. comm.).

Table 7. Mean plant heights, masses, numbers of bolls produced and seed cotton masses produced by infested cotton, 1989/90.

PLANT GROWTH	LEVEL OF INFESTATION				
INDICATOR	0	2	8	12	MEAN
MEAN PLANT HEIGHT (cm)	79.13	67.38	73.00	60.88a	70.09
MEAN PLANT MASS (grams)	176.67	179.38	153.76	127.42	159.31
NO. OF BOLLS PRODUCED	7.63	6.25	5.63	4.38	5.97
SEED COTTON MASS PRODUCED (grams)	20.65	11.06	19.64	8.26	14.90

a Mean differs significantly from other means in row (Bonf. $p < 0.05$); absence of a letter behind means in a row indicates that means do not differ significantly.

Table 7. Mean plant heights, masses, numbers of bolls produced and seed cotton masses produced by infested cotton. 1989/90.

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a Mean differs significantly from other means in row (Bonf. $p < 0.05$); absence of a letter behind means in a row indicates that means do not differ significantly.

Table 8. Fibre quality of each treatment and acceptable ranges.

CHARACTERISTIC	TREATMENT				ACCEPTABLE
	0	2	8	12	RANGE
FIBRE LENGTH (mm)	29.97	29.21	30.22	31.50	28.5 - max
TENACITY (cN/tex)	21.40	22.90	20.90	22.50	22.5 - 23.5
ELONGATION (%)	6.40	6.50	6.30	6.10	6.5 - 8.0
MICRONAIRE (mic.)	3.93	3.60	4.10	3.20	3.2 - 4.6

6.3 Discussion

The results obtained above indicate that reduction in plant height is the most sensitive indicator of cotton plant growth with respect to A. soleatum attack. In addition, cotton yield expressed in terms of numbers of bolls and mass of seed cotton produced, is, as expected, negatively affected by A. soleatum attack. According to Luckman and Metcalf (1982), the term pest is a label applied by man and a pest problem exists because such pests compete with man. They add further that insect pests are generally regarded as destructive or noxious in proportion to their numbers or competition with man. Since A. soleatum has been shown to occur in high numbers and to negatively affect the growth of cotton, thereby reducing boll production, the pest status of this insect is justified.

The results from the 1988/89 season were somewhat confusing to the extent that, for plant height, numbers of lateral branches and boll production, the treatment of 12 A. soleatum per plant gave consistently higher mean values than did the treatment of 8 A. soleatum per plant. The mean values of the former treatment were, however, lower than those for the 5 A. soleatum per plant treatment. The reason for this was the death of a plant exposed to 8 A. soleatum per plant. The

program used for the analysis of variance calculated means based on the treatment totals being divided by the number of all the replications in the treatment. Missing plot values were not computed.

In order to quantify the effect of A. soleatum infestation on plant height and boll production, linear regressions were computed using the mean of each treatment in each season (Figs 38 & 39). The r^2 values were all high, indicating that a linear relationship between plant growth and level of infestation exists. In the case of plant height, the difference in the slopes of each season's regression can probably be ascribed to seasonal variation in weather conditions (Dippenaar 1991, pers. comm.). Seasonal effect was not investigated in the study, but it is notable that during the 1988/89 season, for boll production, plant height, number of lateral branches and plant mass, the controls differed significantly from the other treatments, whereas this was not the case during the following season. The slopes of the regressions reflect this. This would further suggest that seasonal conditions probably interact with the level of A. soleatum infestation to produce yield reductions, a factor which should be considered when establishing an economic threshold for A. soleatum.

The regression equations mentioned above (Figs 38 & 39) were utilised in an attempt to establish an economic threshold. By substituting the Bonferroni LSD for Y in the two equations pertaining to boll production, and solving for X, the number of A. soleatum per plant which caused a significant ($p<0.05$) reduction in boll production, could be determined. For the 1988/89 growing season, the value for X was 4,78 and for the 1989/90 season, 9,14, an almost two-fold (1,912) increase. The same computations were done with respect to plant height and X values were 13,96 for 1988/89 and 30,56 for 1989/90, again an approximately two-fold (2,189) increase. This consistency in the ratio of the two X values suggests

that the growing seasons were different in some respect, probably weather, and that economic thresholds would vary between growing seasons when growing seasons differed from one another.

The different infestations did not produce any recognisable tendencies, either positive or negative in fibre quality. Most of the values fell within the ranges of the quality indicators as given in Table 8 and by De Villiers (1991 pers. comm.). The effect of A. soleatum on cotton is thus apparently confined to growth and yield and not quality.

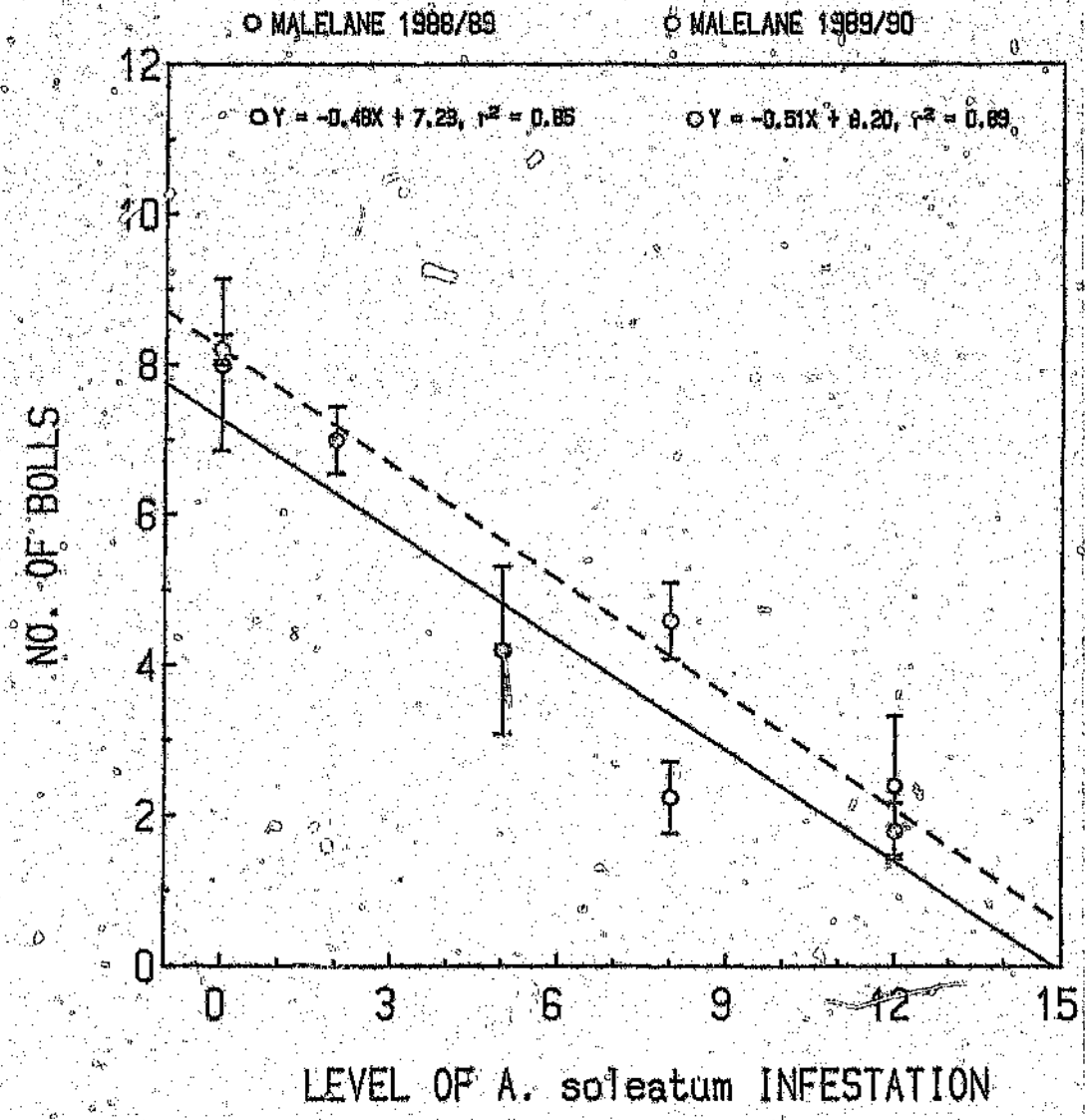


Fig. 38 Linear regression of infestation level against boll production

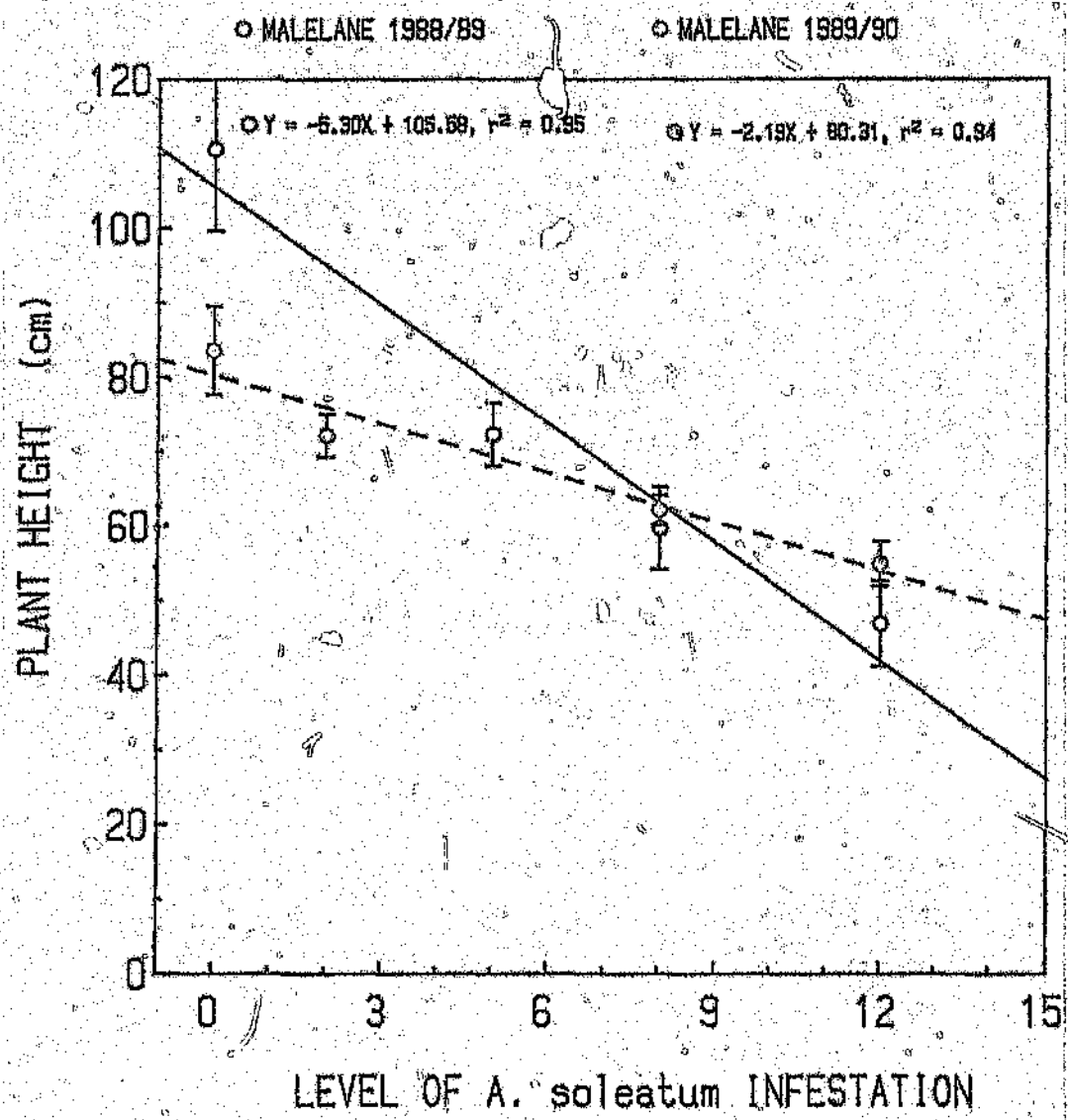


Fig. 39 Linear regression of infestation level against plant height

CHAPTER 7. FEEDING PREFERENCES AND WITHIN-PLANT DISTRIBUTION OF Apion soleatum ON COTTON

7.1 Aims

According to Matthews and Matthews (1978), the obtaining and maintaining of an energy pool, is the major preoccupation of every individual in any species, and Price (1975) cites "food" as being a recurrent theme in insect ecology. The feeding stages of A. soleatum are the adult and the larva and it is reasonable to assume that their feeding activities are responsible for any damage caused to cotton. Knowledge of the feeding activities and within-plant distribution of these stages can aid in the identification of regions in the cotton plant to which pesticide applications can be made, thereby enhancing the efficiency of control. In addition such knowledge may elucidate the type of stress cotton is subjected to as a result of A. soleatum attack. The feeding preferences of the adults, which are mobile, should correlate well with their distribution within cotton plants, whereas the distribution of the apodous larvae, which are not capable of moving any great distance, is probably a function of adult distribution and oviposition preferences.

Several objectives were identified for this part of the study. The first was to determine in which region of the plant and on which plant organs, feeding by adults and larvae occurred, as well as the distribution of the pupae and parasitoid wasp. The second was to identify which of the feeding stages was responsible for yield reductions, and the third was to confirm whether the hypotheses stated in the preceding paragraph were valid or not.

7.2. Methods

7.2.1 The within plant distribution of adults, larvae, pupae and Entedon apionidis.

For the purposes of this investigation the aerial parts of cotton plants were arbitrarily subdivided into a top region (upper third of the plant; 1/3), a middle region (middle third of the plant; 2/3) and a lower region (lower one third of the plant, including the transition zone between root and stem; 3/3). Within these regions, the leaves, stems and lateral branches, and flowers and bolls were investigated for the presence of adults, larvae, pupae and the parasitoid wasp. Plants for investigation were chosen at random from the field of ratoon cotton at Hoechst's experimental farm near Malelane. Examination of plants followed four steps:

i. The identification of the plant to be investigated.

ii. Careful examination of the aerial plant parts and the recording of adults in the three regions.

iii. Removal of the plant to the edge of the field and the division of the stem into the three regions.

iv. The splitting of the stem and lateral branches, and examination of flowers and petioles for pupae, larvae and wasps.

The choice of the statistical test to compare the mean numbers of individuals between regions requires discussion. According to Steel and Torrie (1980), a meaningful comparison of means derived from two or more populations or samples require that the two populations have the same variance. The estimator of this variance (Sy^2) can be seen to vary considerable between the samples derived from the different plant regions (Table 9). Steel and Torrie (1980) give a modified t-test for the comparison of means derived from two samples with unequal

variances, which computes an effective degrees of freedom to compensate for the unequal variances. The test statistic in this case is t', which is compared with values of Students' distribution at the computed effective degrees of freedom. The computed effective degrees of freedom is dependant on the variances of the means being compared.

7.2.2 Feeding preferences of adult A. soleatum

Again, plants were divided into three regions as above. Five leaves of approximately equivalent size and physiological age were selected from each region. An index of leaf damage was determined by computing the ratio between the leaf area fed upon by adult A. soleatum, and the total leaf surface area. Leaf areas were determined by placing leaves on a light table and tracing their outlines onto squared paper, together with the outlines of the holes caused by adult feeding. The leaf area removed by A. soleatum was calculated by determining the mean area of a single hole (n=30) using a Zeiss calibration slide under a stereo microscope, and multiplying it by the number of holes in the leaf. It was necessary to form such a ratio because leaf areas varied. In comparing leaves of approximately three different physiological states and physical position, it was hoped to show which parts of the plant A. soleatum adults prefer feeding upon. The statistical test for samples with unequal variances was used to compare means.

7.2.3 Larval feeding

Transverse sections of cotton plant stems infected with A. soleatum were made with a razor blade and stained with toluidine blue (O'Brien et al. 1964). These were examined under a microscope to determine which plant tissues were fed upon.

7.3 Results

7.3.1 Within plant distribution of adults, larvae, pupae and Entedon apionidis.

The means together with the statistical calculations are presented in Table 9. Significantly ($p<0.05$) more adults were found in the uppermost third of the cotton plants than in the middle third. There was no significant difference in the numbers of adults found on the top (1/3) and lower (3/3) parts of the plants. In addition adults were found on the stems and leaves and very rarely on the bolls and flowers. The pupae were distributed predominantly over the upper two-thirds of the plant. Larvae appear to be evenly distributed over the entire plant. With respect to the parasitoid, it is interesting to note that their distribution appears to follow that of the adult.

7.3.2 Feeding preferences of adult Aplon soleatum

Proportionately more leaf area is removed by adult A. soleatum in the upper parts of the plant. A gradient in feeding activity occurs with proportionately less leaf area being removed as one moves lower on the plant. The results are presented in Table 10. Each mean was derived from 75 leaves.

7.3.3 Larval feeding

Larvae are found predominantly under the bark of the stem, near the axils of lateral branches. The plant tissues which are fed upon are the phloem and secondary xylem (Fig. 40). The secondary xylem becomes discoloured in patches centrad of the region which has been fed upon (Fig. 41). Secondary metaxylem vessels appear to be particularly susceptible to discolouration (Fig. 42).

Table 9. Within plant distribution of A. soleatum and E. apionidis.

	ADULTS			PUPAE			LARVAE			E. apionidis		
	1/3	2/3	3/3	1/3	2/3	3/3	1/3	2/3	3/3	1/3	2/3	3/3
MEAN	2.600	1.200	2.000	1.467	0.667	0.466	7.200	4.600	8.730	2.467	0.933	1.600
ΣY	39.00	18.000	30.00	22.00	10.00	7.00	108.00	69.00	131.00	37.00	14.00	24.00
ΣY^2	179.00	78.00	144.00	68.00	14.00	11.00	1260.00	523.00	2147.00	129.00	24.00	68.00
Sy^2	5.5428	4.0?96	6.0000	2.5524	0.5238	0.5524	34.4287	14.6860	71.6386	2.6950	0.7809	2.1143
COMPARISON	1 vs 2	2 vs 3	1 vs 3	1 vs 2	2 vs 3	1 vs 3	1 vs 2	2 vs 3	1 vs 3	1 vs 2	2 vs 3	1 vs 3
Sy1-y2	' '998	0.8182	0.8770	0.4529	0.2679	0.4550	1.8095	2.4690	2.8407	0.4814	0.4512	0.5751
t^1	1.7520	0.9780	0.6840	1.7664	0.1068	4.3956	1.4370	1.6606	0.5386	3.1865	1.47?3	1.5076
EFF. df^2	27	27	28	20	28	20	24	19	26	21	23	28
SIGNIFICANCE	p<0.05	NS	NS	p<0.05	NS	p<0.01	NS	NS	NS	p<0.01	NS	NS

Table 10. Percentage leaf areas removed by adult A. soleatum.

PERCENTAGE LEAF AREAS REMOVED BY A. soleatum			
	PLANT REGION		
	1/3	2/3	3/3
MEAN	2.2863	1.3685	0.7176
Σy	34.2950	20.5280	10.7643
Σy^2	104.6048	43.9705	14.3878
Sy^2	1.8710	1.1341	0.4759
COMPARISON	1 vs 2	2 vs 3	1 vs 3
Sy1-y2	0.4476	0.3276	0.3956
t'	1.6464	2.0089	3.5269
EFF. df	26	24	21
SIGNIFICANCE	p<0.10	p<0.05	p<0.01

7.4 Discussion

Adults of A. soleatum are to be found on all aerial parts of the cotton plant, however they tend to be most active in the upper one third, where the developing leaves occur. According to Ting (1982), young developing leaves near the apex of the plant are a sink for carbohydrates produced by photosynthesis. Translocation out of these rapidly expanding leaves is limited and the photosynthates produced in them are retained. This is may be the reason why adult densities are higher apically. This phenomenon can be utilized when the application of an insecticide is required for the control of this insect. Contact insecticides applied to the canopy will probably be more effective and certainly easier to effect, than their application to other regions. The areas of leaves removed by adults during feeding are small in comparison with total leaf area. It would therefore appear unlikely that the adult stage is responsible for yield or quality losses. Of further note is the fact that no evidence of adult feeding was ever found to have occurred

on the flowers or bolls. This contrasts with the observations made by Broodryk and Mansfield (1985).

In contrast, larval feeding on the translocatory tissues of the stem and lateral branches is probably the chief cause of yield reductions. Not only are parts of the phloem and xylem removed where the larva feeds, but relatively large areas of the xylem become discoloured. Toluidine blue, the stain used in this investigation, stains lignin blue-green (O'Brien et al. 1964). The fact that vessels in the discoloured regions did not stain blue-green indicates that the lignin-lining of these vessels was affected in some way. It would seem that larval feeding affects the xylem translocation system in the plant, which in turn explains the reduction in growth (Chapter 7) of cotton plants infected with A. soleatum. The larvae of A. soleatum constitute the damaging stage of this insect. In addition to affecting plant growth, larval feeding weakens the stem and infected branches, which may result in the collapse of the plant as maturing bolls become too heavy (Bennett and Nel 1990). The age of the plant when it becomes infected determines to a large extent whether yield reductions are caused by weakening of the plant frame, or inhibition of plant growth. Infestation of young cotton results in growth being affected and consequently the production of bolls by the plant is reduced. Infestation of older plants may result in yield losses due to the physical weakening of the plant frame. Such losses may be aggravated by high winds.

The distribution of the parasitoid, Entedon apionidis, follows that of the adults and the larvae, and is probably a function of its searching behaviour. The data gathered supports this hypothesis. Adults presumably oviposit in the upper third of the plant. As the plant grows, developing larvae are distributed over the whole plant. The parasitoid larvae are associated with the larvae and pupae of A. soleatum (Bennett & Nel 1990), but the adult parasitoids follow adult A. soleatum

distributions in order to locate either eggs or young larvae, in which to oviposit.

The existence of this parasitoid will complicate control strategies for A. soleatum should they become necessary on a large scale. Older cotton infested with A. soleatum is invariable populated with E. apionidis as well (Bennett & Nel 1990), and in devising a strategy to control larval A. soleatum, special consideration will have to be taken of E. apionidis. According to Samways (1981), chemicals must be used judiciously so as not to kill natural enemies. The pesticide chosen for A. soleatum control should be such that it is not very effective against E. apionidis. In addition, the area of application must be carefully chosen so that E. apionidis is not exposed to unnecessarily high concentrations or volumes of the pesticide. Systemic insecticides would undoubtably be effective in controlling the larvae of A. soleatum, however, they would probably be just as effective against E. apionidis larvae, which occur together with A. soleatum larvae in the stem tunnels. A non-systemic, contact insecticide, applied to the top one third of cotton plants, where adults tend to occur, appears to be the best option for control. Even though adult E. apionidis tend to be distributed with adult A. soleatum, they do not feed on the cotton leaves, and would thus avoid receiving the same doses as the weevils.

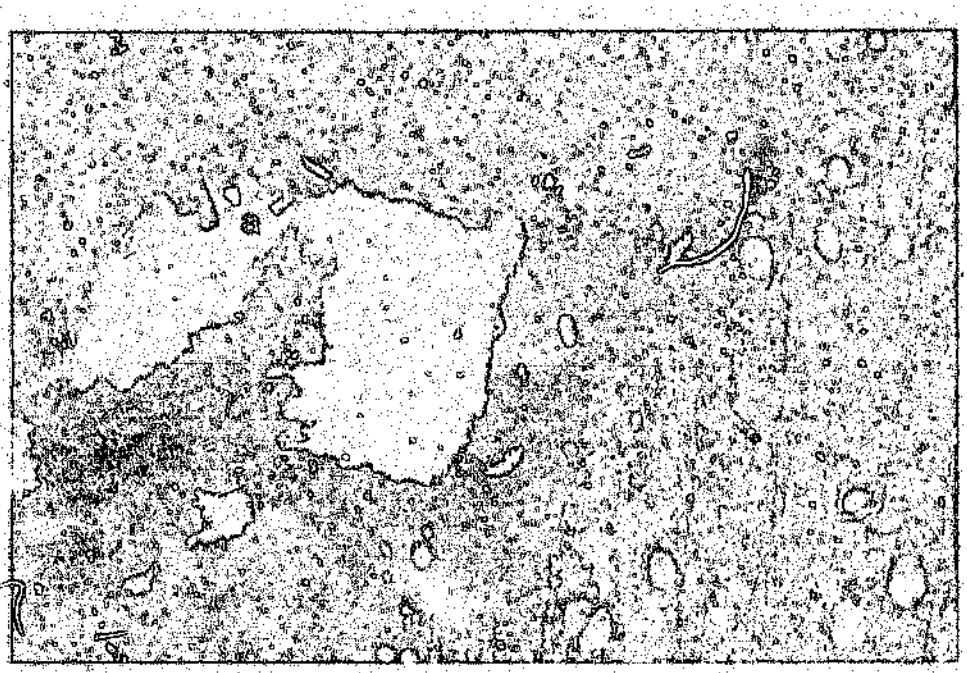


Fig. 40 Larval feeding on phloem and secondary xylem.

T/S cotton stem a phloem b xylem

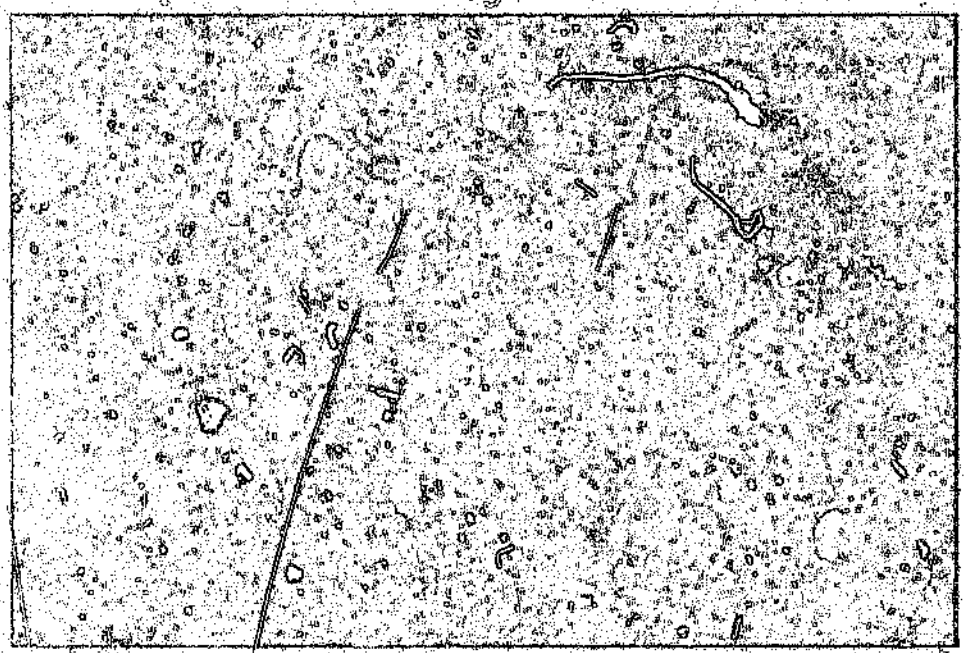
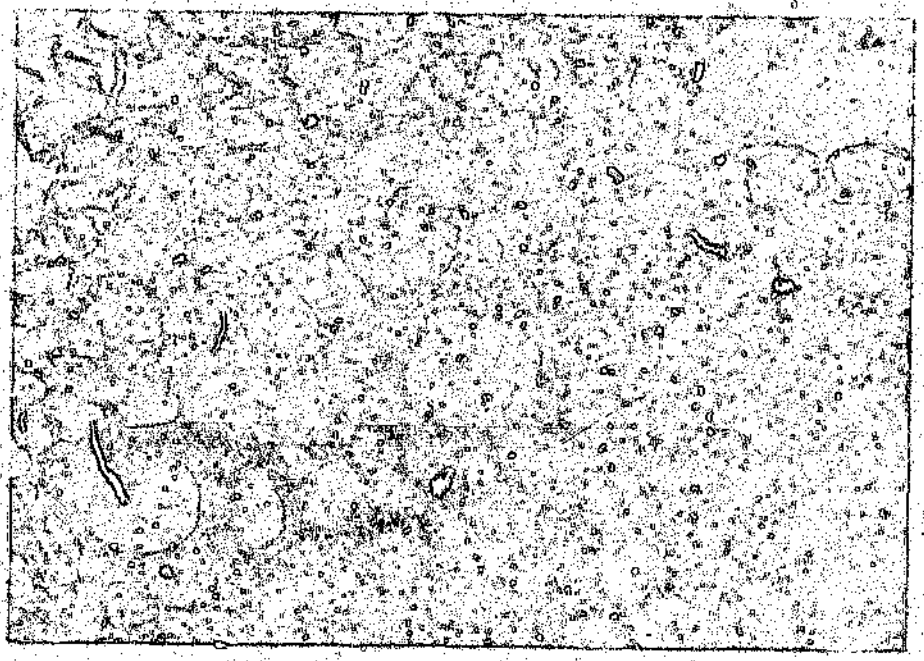
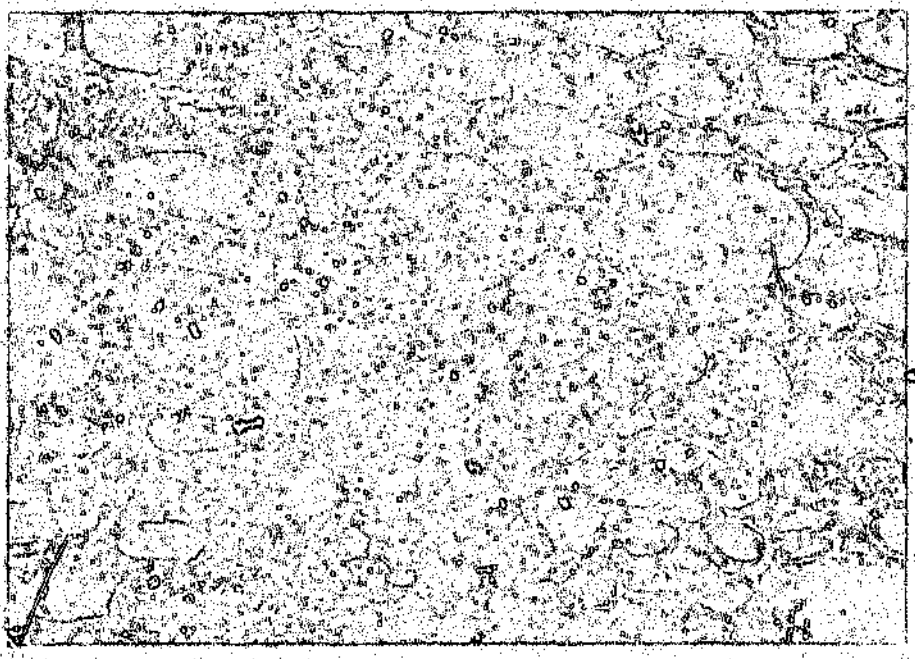


Fig. 41 Discolouration of secondary xylem. T/S cotton stem



a. Infested cotton plant



b. Uninfested cotton plant

Fig. 42 Secondary metaxylem. T/S cotton stem

CHAPTER 8. CONCLUSIONS

"Reason, or the Ratio of all we have already known, is not the same as it shall be when we know more"

William Blake

The findings of the study are listed below.

1. Modern systematists would appear to agree that the apionids should be categorized as a family, that is the Apionidae, and not retained as a subfamily of the Curculionidae, although the latter course was followed in the last major revision of this group (Kissinger 1968).

2. A. soleatum possesses features which place it firmly within the Apionidae. In addition, it possesses a number of features which clearly exclude it from the genus Apion Herbst. In the opinion of Alonzo-Zarazaga (1988, pers. comm.) this species may represent a new genus, somewhat similar to Caenapion Voss. According to Alonzo-Zarazaga (1988, pers. comm.), the species now known as A. soleatum may fall into the new genus Lonchaspis which he is currently describing (Appendix A).

3. A. soleatum occurs only in the eastern Transvaal and northern Natal regions, which account for approximately ten percent of South Africa's total cotton production.

4. The life cycle of A. soleatum includes the egg, three larval instars, the pupa and the adult. Eggs are laid in the cotton stem, where larval and pupal development takes place. Adults feed on cotton leaves.

5. E. apionidis (Hymenoptera: Eulophidae), a parasitoid wasp, attacks the larvae and pupae of A. soleatum, and is generally present where A. soleatum occurs.

6. Cultivated cotton is the major plant host of A. soleatum, and there is no evidence that natural host plants exist.

7. The infestation of cultivated cotton by A. soleatum negatively influences its growth and yield. No evidence to suggest that fibre quality is affected exists.

8. The larva of A. soleatum is the damaging stage. Larvae affect the major translocation systems within the plant, resulting in poor plant growth. Adults are found predominantly near the apex of plants, where the nutritional value of the leaves is higher.

A. soleatum does justify pest status. However its impact on the cotton industry in South Africa is likely to be negligible. Firstly, it does not occur in the regions where approximately 90 percent of South Africa's cotton is produced. Over the past five years or so, its distribution has remained constant. Secondly, a biological control agent is present in the regions where A. soleatum occurs, and thirdly, the implementation of sound cultural practices, such as avoiding ratoon cotton, also assists in the control of this insect.

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APPENDIX A.

(21)

Mr. Andrew Bennett
Tobacco and Cotton Research Institute
Dept. of Agriculture and Water Supply,
Private Bag X82075
0300 Rustenburg
Rep. of Southern Africa

Málaga, 14.XI.1988

Dear Mr. Bennett:

I was very glad to receive your letter dated 6.X.1988. I had some news about you from my friend Rolf Oberprieler, but in fact both of us were so busy that we had banish the Apion scleratum affair from our minds, I am afraid.

I received from Rolf some time ago a few specimens taken at Shinyakana-Pigtree (Kanyange) by J. Mansfield (1 males plus one vial containing larvae, pupae and immatures) and one male plus 2 females from Komatipoort taken by S. W. Broodryk. I am afraid that all these specimens were immatures and not useful for taxonomic studies. As Rolf Oberprieler perhaps has told you, I am mainly interested in the Systematics of World Apionidae. I have finished a paper on the supragenerio taxa of Palaearctic Apionidae, and I was trying to compare this survey with the Tricnemus species when I run into this species.

I consider that it may represent a different genus (in fact it is not a true Apion, this being exclusively a Palaearctic genus). Unfortunately I could not dissect well these tender specimens, and I am used to describe fully the new taxa I name. The new genus is rather similar to Cnemapion Voss, whose type species I studied some time ago in relation with the description of this new genus (Longhaspis in litt.).

I carried with me some specimens when I went to the British Museum (London) in January 1988 and compared them there with specimens of Apion scleratum and xanthostylum. All of them were conspecific.

I am aware of your reference list excepting le Pelley's one. The only ones I have in addition are those concerning the original descriptions (which I suppose you have got) and the following reference:

Wagner H, 1912. Coleoptera fam. Curculionidae subfam. Apioninae. In Wytsman, Genera Insectorum, 130: 1-109 + 6 pl.

This is just another catalogue like that of 1910. Both species were listed as different, recording only the original description.

I would like to get some dry, ethyl acetate-killed, mature specimens for dissection from you to put an end to this work I began almost three years ago. Specimens stored in alcool are not useful. If you want, you could also store them in a 10% solution of Hexaryl Lauryle (a skin disinfectant soap to be found in a chemist's; it is the best thing to keep insects stored as recently captured for years).

I would also like to get a photocopy of the part dealing with Curculionoids of le Pelley's book.

I am at your disposal for identification of Apionidae (incl. Nanophyinae), and secondarily, Attelabidae and Rhynchitidae. I would be very glad if you could send me from time to time specimens of these families for my collection, and I would name them for you. I am very interested in host plant data for these specimens. I am mostly interested in Proteaceae inhabiting Apionids, for I am currently revising the tribe Taeniini, all of its species seemingly live on this plant family.

Thank you for your kindness. Yours sincerely

Miguel A. Alonso-Zarazaga (Dr.)
Carretera de Cádiz, 89, 1ºA (Edif.S.Joaquín)
29004 Málaga SPAIN
Tel. (9)-52-328134

1.4.90

APPENDIX B.

Mr./Andrew Bennett
Tobacco and Cotton Research Institute
Private Bag X 82075
Rustenburg 0300
Republic of South Africa

Maputo, 27th February 1990

Dear Sir,

Thank you for your letter dated 8 November 1989 regarding the cotton stem weevil occurence in Mozambique.

Mr Narciso Rodrigues, entomologist at the Cotton Secretariat informed me that he had no knowledge, so far, of the presence of this pest in cotton fields in Mozambique, and a confirmation of that should be done.

In 1968 a list of crop pests in Mozambique was published. As per this information there are four Apion spp. listed as cotton pests , the first three considered to be of great economic importance at that time:

1. Apion asphaltinum
2. A. consimile
3. A. constrictum
4. A. considerandum

In the INIA (National Institute of Agronomic Research) insect collection there are a few specimens of the first two listed above and also of A. xanthosthym and others non identified Apion species, collected on cotton during the years 1943-1956. There are only a few specimens in that collection and INIA will not let them out and so I cannot send any to you.

"Besouro" is a common name given to all Coleopteran insects in portuguese literature and there is no specific connection between this name and Apion soleatum.

This is all I can inform you now about this subject and I will write to you if I get any other information .

I would be very happy if you can send me any recent literature on this subject especially the aspects of biology and taxonomy of the above mentioned insects.

Yours sincerely,

Luisa Alcantara

Luisa Alcantara Santos
Faculty of Agronomy
Eduardo Mondlane University, PO Box 257
Maputo, Mozambique

APPENDIX C.

Analyses of variance for 1988/89: Maielane.

Table I. Factorial analysis of cotton plant height.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replication	3	1123.34	374.45	1.03	3.07
Time of infestation	1	810.03	810.03	2.24	4.32
Level of infestation	3	11682.09	3894.03	10.78	3.07
Interaction	3	1969.34	656.45	1.81	3.07
Error	21	7586.25	361.25		
Total	31	22047.72	711.22		

Table II. Factorial analysis of cotton plant mass.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	3	207558.06	69186.03	1.59	3.07
Time of infestation	1	231223.22	231223.22	5.32	4.32
Level of infestation	3	707836.66	235945.60	5.43	3.07
Interaction	3	227513.90	75837.97	1.74	3.07
Error	21	913084.10	43480.20		
Total	31	2079657.88	67085.74		

Table III. Factorial analysis of number of lateral branches.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	3	7.85	2.62	0.61	3.07
Time of infestation	1	26.24	26.24	6.11	4.32
Level of infestation	3	146.03	48.67	11.34	3.07
Interaction	3	43.60	14.53	3.38	3.07
Error	21	90.15	4.29		
Total	31	306.03	9.87		

Table IV. Factorial analysis of boll production.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	3	82.54	27.51	2.15	3.07
Time of infestation	1	38.24	38.24	2.99	4.32
Level of infestation	3	237.51	79.17	6.19	3.07
Interaction	3	34.62	11.53	0.90	3.07
Error	21	268.46	12.78		
Total	31	578.83	18.67		

Analyses of variance for 1989/90.

Table V. Analysis of plant heights.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	7	2296.97	328.14	3.88	2.49
Levels of infestation	3	1459.09	486.36	5.76	3.07
Error	21	1774.66	84.51		
Total	31	5530.72	178.41		

Table VI. Analysis of plant masses.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	7	41507.48	5929.64	1.43	2.49
Levels of infestation	3	14017.23	4672.41	1.13	3.07
Error	21	86818.99	4134.24		
Total	31	142343.70	4591.73		

Table VII. Analysis of plant boll production.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	7	35.23	5.03	0.87	2.49
Levels of infestation	3	43.84	14.61	2.51	3.07
Error	21	121.91	5.81		
Total	31	200.97	6.48		

Table VIII. Analysis of seed cotton mass produced.

SOURCE	DF	SS	MS	CALC. F	TAB. F
Replications	7	1112.71	158.67	1.61	2.49
Levels of infestation	3	914.06	304.69	3.11	3.07
Error	21	2057.69	97.99		
Total	31	4082.46	131.69		