FIELD BIOLOGY AND IDENTIFICATION OF FRUIT FLIES IN THE WESTERN CAPE PROVINCE

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DECLARATION

I, the undersigned hereby declare that the work in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree.

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ABSTRACT

Two fruit fly species, *Ceratitis capitata* (Wiedemann) and *C. rosa* (Karsch) (Diptera: Tephritidae) are known to attack deciduous fruit in the Western Cape Province of South Africa. The relative abundance of these two pests was studied in different kinds of fruit throughout the year.

To facilitate field monitoring, using the immature stages, morphological differences between larval instars of *C. capitata* and *C. rosa* were investigated. Morphological characters of the larvae, such as the spiracles (anterior and posterior), mouthhooks and oral ridges were used. Many of these characters are only suitable to distinguish between the second and third instar larvae as these structures are not yet developed in the first instar larvae. Anterior spiracles were examined in terms of the number of tubules (papillae) and size or shape of the felt chambers. The number of papillae in both species was similar in the second and third instar larvae, but differed between the larvae of the two species (8-10 for *C. capitata* and 10-13 for *C. rosa*). In both species the felt chambers of the second instar larvae were narrow and elongate whilst those of the third instar larvae were broad and short. The major difference between the mouthhooks of the two tephritids was the presence of a sub-apical tooth in the third instar larva of *C. rosa*, being absent in the third instar of *C. capitata*.

For the morphometric study, both laboratory-reared and field-collected specimens were examined. Measurements of the body dimensions (length and width) and various parts of the cephalopharyngeal skeleton (CPS) (mandible base, mandible length and distance between the tip and notch) were recorded in all three instars of both *C. capitata* and *C. rosa*. The data were analysed using finite mixture analysis (FMA-N1) and Levene's test was used to test for homogeneity of variances. The results of these

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analyses were used to estimate the frequency distributions of the larval measurements. In some cases overlaps in distributions were evident and were resolved using the same program, finite mixture analysis (FMA-N1), based on the probability of the overlapping measurements belonging to the designated instar (i.e. the one with highest probability). Determination of growth ratios suggested an approximate conformation to Dyar's rule thereby disputing the possibility of any hidden instar. However, in most cases measurements of the field samples did not conform to Dyar's rule.

For the larval instars of *C. capitata* and *C. rosa* with overlapping morphological features, the morphometric approach as a distinguishing tool was demonstrated. In the field survey, the relative abundance of *C. rosa* at all experimental sites was very low in both orchards and adjacent vines. This suggested that this pest was either not a threat in these sites (crops) or the monitoring procedures applied, should be revised. Trap catches indicated high levels of infestation by *C. capitata* on some sites and low infestation levels at others. On the site with the highest population levels, activity peaks in the orchards did not co-incide with those in the adjacent vineyards. This suggested that these vineyards could be alternative hosts for fruit fly after the fruit in the orchards have been harvested.

Forced oviposition (*in vitro*) studies indicated that Colombard (grown in Simonsvlei) was the most suitable host for survival of *C. capitata*. Other wine grape cultivars such as Chardonnay were also suitable for the total larval development of *C. capitata*.

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OPSOMMING

Twee spesies van die vrugtevlieg, *Ceratitis capitata* (Wiedemann) en *C. rosa* (Karsch) (Diptera: Tephritidae), val sagtevrugte in die Wes Kaap Provinsie van Suid-Afrika aan. Die groot hoeveelheid van hierdie twee plae op verskillende soorte vrugte is regdeur die jaar bestudeer.

Voordat enige insekplaag gemonitor kan word, is dit belangrik dat die identiteit van die besondere plaag, insluitend sy onvolwasse stadiums, bekend moet wees. In hierdie studie word die morfologiese verskille tussen die larwe stadiums van *C. capitata* en *C. rosa* ondersoek.

Kenmerke soos die spirakels (voor en agter), mondhake en mondriwwe is gebruik. Baie van hierdie morfologiese kenmerke kan net gebruik word om te onderskei tussen larwes in die tweede en derde stadiums omdat hierdie strukture nog nie in die eerste stadium ontwikkel is nie. Die voorste spirakels is ondersoek in terme van die aantal tubules (papillae) en die grootte en vorm van die vilt kamers. In beide spesies is die aantal papillae dieselfde vir die tweede en derde larwe stadiums, maar daar was 'n verskil tussen die larwes van die twee spesies (8-10 vir *C. capitata* en 10-13 vir *C. rosa*). In altwee spesies was die vilt kamers van die twee stadium larwes smal en verleng, terwyl dit in die derde stadium larwes breed en kort was. Die hoof verskil tussen die mondhake van die twee vrugtevlieë was die aanwesigheid van die subapikale tand in die derde stadium larwe van *C. rosa*, terwyl dit afwesig is in die derde stadium van *C. capitata*.

Vir die morfometriese studie is voorbeelde van laboratorium geteelde vrugtevlieë, asook vileë wat in die veld gevind is, ondersoek. Die liggaamsafmetings (lengte en breedte) is gemeet asook die skelet (mandibel basis, mandibel lengte en die afstand

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tussen die punt en die kerf) in al drie stadiums van *C. capitata* en *C. rosa*. Die data is ontleed deur middel van eindige mengsel analise (FMA-N1) en Levene se toets is gebruik om vir homogeniteit en variansies te toets. Die resultate van die ontleding is gebruik om die frekwensie verspreiding van die larwale metings te skat. In sommige gevalle was daar oorvleueling en dit is opgelos met die gebruik van dieselfde program FMA-N1 baseer op die moontlikheid dat die metings wat oorvleuel, aan die aangeduide stadium (d.w.s die een met die hoogste waarskynlikheid) behoort. Die vasstelling van groei ratios dui aan dat dit naasteby ooreenstem met Dyar se reel en dus die moontlikheid van 'n versteekte stadium betwis. Maar in die meeste gevalle stem die veldmonsters nie ooreen met Dyar se reel nie.

Die feit dat die morfometriese benadering die vermoë het om larwale monsters met oorvleuelende morfologiese kenmerke, beteken dat dit kwalifiseer as 'n instrument om tussen die larwe stadiums van *C. capitata* en *C. rosa* te onderskei. Baie min *C. rosa* is in vrugteboorde en in nabygeleë wingerde gevind. Dit dui òf dat die plaag nie 'n bedreiging vir die vrugte inhou nie, òf dat die monitor prosedures hersien moet word. Lokvalle dui aan dat daar 'n hoë vlak van infestasie van *C. capitata* in sommige gebeide is en 'n lae vlak in ander. Op die plek met die hoogste bevolking van vrugtevlieë het die aktiwiteit in die boorde nie ooreengestem met die aktiwiteit in die nabygeleë wingerde nie. Dit dui aan dat hierdie wingerde 'n alternatiewe blyplek bied aan die vrugtevlieë nadat die vrugte in die boorde geoes is.

Gedwonge oviposisie studies dui aan dat *C. capitata* die beste kan oorleef in Colombard (gekweek te Simonsvlei). Ander wyndruif kultivars is ook geskik vir die ontwikkeling tot by die laaste larwe stadium van *C. capitata*.

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DEDICATIONS

To my late blood-brother, Bongani, who taught me to live the dream but could not see this work when finished. 'Lala ngoxolo Ndondela, thina basele siya phambili'. This work is also dedicated to my father, Nyanisile July Hobololo, my mother Anna Mamokete Hobololo, my sister Bongiwe, my brother S'busiso and my nephew Musawenkosi Hobololo.

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CHAPTER 1

FIELD BIOLOGY AND IDENTIFICATION OF FRUIT FLIES IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA: A REVIEW

1.1 INTRODUCTION

The family Tephritidae, the true fruit flies, includes about 4000 species arranged in 500 genera (White & Elson-Harris 1992). It is one of the largest and economically most important families of Diptera. The larvae of most species develop in the seed-bearing organs of plants and about 35% of species attack soft fruits, including many commercial crops. Two fruit fly species, *Ceratitis capitata* (Wiedemann) and *C. rosa* (Karsch), are major pests of the deciduous fruit industry in the Western Cape Province of South Africa. The current status of Tephritidae taxonomy relies exclusively on adult characters (Greene 1929; Foote 1980; White & Elson-Harris 1992).

This chapter provides a general overview and critical evaluation of the published literature with particular reference to *C. capitata* and *C. rosa*, together with a motivation for conducting the current study. The objectives of this study were to identify morphological differences between the larval instars of *C. capitata* and *C. rosa*, and to provide descriptions and identification keys thereof.

1.2 GENERAL OVERVIEW OF TEPHRITIDIDS

The Tephritidae is a large family of small to medium-sized picture-winged flies. The wings are usually spotted or banded, the apex of the subcosta is bent abruptly forward at

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almost a right angle, and the seventh segment of the female abdomen is long and chitinized. Adults are usually found on vegetation. The larvae are typical maggots, pointed anteriorly and truncated posteriorly with two terminal spiracles. Larvae are of major importance since they feed in fruit, flowers, seeds and stems, and in some cases galls may be induced. *C. capitata* and *C. rosa* are polyphagous and attack many subtropical and deciduous fruits. Fruits may suffer either direct damage due to larval feeding, or subsequent indirect injury due to fungal infection. Tephritids may also attack other commercial crops and the flower heads of ornamental plants.

1.3 GENERAL DESCRIPTION OF TEPHRITID IMMATURE STAGES

1.3.1 Egg: Egg colour is usually glistening white to creamy-yellow, becoming slightly darker towards the time of eclosure. The shape and size of eggs vary according to species; for example, the eggs of *Bactrocera tryoni* (Froggatt) and *C. capitata* are elongate and gently tapering whereas those of *Urophora solstitialis* are rounded at the anterior end and posteriorly long and pointed (Ferrar 1987). At the anterior end of the egg is a small micropyle which is obvious in most species and very pronounced in the tribe Terrellini. In some *Chaetorellia* spp. the micropyle is situated at the end of a tubular extension of the egg. This extension may be up to twice as long as the main body of the egg (White & Marquadt 1989). The surface or chorion of the egg usually appears smooth when viewed under the light microscope. However, at high magnification, using the scanning electron microscope (SEM), a polygonal pattern is usually visible, which probably represents the boundaries of the follicle cells (Margaritis 1985).

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1.3.2 Larva: Tephritid larvae are variable in shape and size depending on species and availability of essential nutrients in the breeding media. Larvae of Dacinae and Trypetinae that develop in soft fruits are usually maggot-like, with abdominal segment eight truncated and the rest of the body tapered towards the anterior end. Larvae of Tephritinae tend to be cylindrical and rounded or almost truncated at both ends of the body. Mature larvae are usually creamy-white, although some may appear darker due to gut contents showing through the cuticle. The cuticle is almost translucent, without pigment or sclerotization and the surface is frequently ornamented with numerous rounded projections or small sharply pointed spinules. A tephritid larva has a small tapered head with two distinct black dots (the heavily sclerotized mouthhooks), three thoracic and eight abdominal segments.

1.3.2.1 First instar: First instar larvae are extremely small, almost translucent, with little surface sculpturing. Some *Urophora* spp. complete the first instar within the egg and emerge as second instar larvae (White & Korneyev 1989). Antennal and maxillary sensory organs are well-developed and clearly defined. Stomal sensory organs are small, while oral ridges and accessory plates are absent. The cephalopharyngeal skeleton is only weakly sclerotized, with mouthhooks yellow to pale amber and the remainder of the skeleton slightly darker. The mouthhooks usually have one or more larger pre-apical teeth. The hypopharyngeal sclerite is fused to the pharyngeal sclerite and the cornuae are only weakly sclerotized.

Body surface sculpturing and spination is much reduced. Individual spinules in comparison to subsequent instars may appear larger. The anterior spiracles appear as minute pores which are only discernible under high magnification using a SEM. There are

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two spiracular openings which may be rounded or slit-like on the posterior spiracles. Four spiracular hair bundles, each with a few relatively long hairs, are present. There are prominent anal lobes, surrounded by large, stout spinules or small rounded projections around the anal opening.

1.3.2.2 Second instar: Larvae are generally creamy-white (although some are discoloured due to food in the intestines) and very similar to, though smaller than, the third instar of the same species.

Antennal and maxillary sensory organs are similar to those of the third instar. Usually the stomal sensory organs are slightly smaller and there are fewer oral ridges. Accessory plates are absent and the face mask is reduced. The cephalopharyngeal skeleton is also very similar to that of the third instar, but the mouthhooks have one or more pre-apical teeth and the hypopharyngeal sclerite is by comparison much longer. The dorsal cornua may have a distal cleft and in some species the ventral cornua has a large window (large, unsclerotized area).

Compared to the third instar, body surface sculpturing and spination is reduced although individual spinules may appear larger. The anterior spiracles are well developed and similar to those of the third instar. The number of tubules usually corresponds to those of the third instar. The posterior spiracles are similar to those of the third instar with three spiracular slits (except in *Myopites* spp. which have two) surrounded by sclerotized rimae. Four spiracular hair bundles are present but there are fewer hairs per bundle. In fruit feeders, the anal area has distinct anal lobes with reduced numbers of spinules surrounding the lobes of the anal opening.

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1.3.2.3 Third instar: The head segment is bilobed anteriorly with two pairs of small, but well defined, sensory structures on lobes previously assigned a variety of names including anterior and posterior sense organs (Snodgrass 1924; Phillips 1946; Exley 1955). These structures are usually referred to as the antennal sensory organs and maxillary sensory organs. Each antennal sensory organ has one to three segments, sometimes lightly sclerotized, with a large basal segment and a cone-shaped distal segment. The maxillary sensory organs lie just below the antennal sensory organs and consist of a broadly flattened segment usually with two well-defined sensilla surrounded by folds of cuticle.

The mouth opening is ventral with small projecting mouthhooks referred to as mandibles by Teskey (1981). Anterolaterally to the mouthhooks lie the stomal sensory organs with several small sensilla. The mouthhooks are surrounded by a series of pre-oral lobes which may be entire (unserrated) or toothed on the lower edges or posterior margins. In some genera, e.g. *Rhagoletis* and *Carpomya*, additional, often heavily sclerotized, pre-oral teeth, or finger-like processes, occur at the base of the stomal sensory organ (Kandybina 1977). At each side of the mouth opening a series of transverse radiating furrows or oral ridges is present. These may be entire (unserrated) or toothed on their posterior margins. Frequently in fruit feeding larvae, an additional series of small accessory plates are present along the outer edge of the oral ridges. A cellular or reticular face mask, incorporating the area of the head around the antennal and maxillary sensory organs and part of the mouth, is present in some Trypetini, e.g. in some *Anomoia*, *Acidiella* and *Myoleja* spp. (Kandybina 1977). This cellular-like structure is absent in the major fruit fly pest genera.

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The cephalopharyngeal skeleton has stout, heavily sclerotized mouthhooks which in *Bactrocera* are usually strongly curved apically, but lack pre-apical teeth. In a few species, e.g. *Bactrocera cucumis* (French) and *B. cucurbitae* (Coquillett), a small vestigial pre-apical tooth is visible. In *Dacus* spp., Tephritinae and Trypetinae, one, or sometimes two, pre-apical teeth may be present. The leaf miner *Euleia heraclei* (Linnaeus) has two pre-apical teeth as well as some additional cuticular teeth around the mouth (Ferrar 1987).

Posteriorly, the mouthhooks articulate with the hypopharyngeal sclerite, also known as the hypostome, hypostomium, hypostomal piece or intermediate sclerite in descriptions by Efflauton (1927), Phillips (1946) and Ferrar (1987), respectively. Parastomal bars, in the form of long, rod-shaped sclerites lying dorsally and parallel to the hypopharyngeal sclerite, are common in fruit-infesting species like *B. tryoni* (Froggatt) and *Rhagoletis pomonella* (Walsh). Labial sclerites form a V-shape in the floor of the mouth between the hypopharyngeal sclerites and the mouthhooks. These sclerites are also known as subhypostomal and ligulate sclerites (Exley 1955; Ferrar 1987). The labial sclerites are small in the tribe Dacini, but much larger in Tephritinae. Another pair of small sclerites, lying close to the mouthhooks, are dental sclerites (sometimes called dentite sclerites) common in Dacini, but absent or inconspicuous in other groups. The lateral walls of the pharynx are supported by sclerotized structures referred to as dorsal and ventral cornuae. The dorsal cornua, also known as the dorsal wing plate (Exley 1955), frequently has a distal cleft and is shorter and thinner than the ventral bridge, sometimes referred to as the dorsal arch (Exley 1955). In non-fruit feeding species the dorsal cornuae are equal to or longer than the ventral cornuae. The dorsal bridge may be present in some and absent in other species. In the Dacini, and in some *Anastrepha* spp., an additional sclerite, the

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anterior sclerite (first mentioned by Exley 1955), occurs on either side of the pharyngeal sclerite, projecting anteriorly from just below the dorsal bridge. On the body, surface sculpturing or spination is very variable in tephritid larvae. Fruit infesting larvae, such as *B. tryoni*, frequently have encircling anterior bands of sharply pointed, posteriorly directed spinules on each thoracic segment. Although in some *Anastrepha* and *Rhagolettis* spp. there are dorsal spinules on the abdomen, most species have only transverse rows of spinules ventrally. These form creeping welts with the first few rows of spinules anteriorly and the remainder posteriorly directed.

Tephritines with gall-inducing larvae usually lack long, sharply pointed spinules although some have small, knob-like structures often forming a surface covering, giving rise to a stippled appearance, or forming reduced patches in particular areas. Anterior spiracles project laterally on each side of the first thoracic segment.

The number of tubules in each anterior spiracle ranges from two to over 50. However, it is usually of limited use taxonomically, as the number of tubules may vary widely within a species. An exception is the separation of *R. cingulata* (Loew) from *R. indifferens* (Curran), where the number of spiracular tubules provides better separation than any other larval character. Generally, gall-inducing larvae have a low number of spiracular tubules, which are often set in a fan-shaped arrangement. In other species, rows of tubules will often bifurcate and in some root, leaf and stem-mining species there are multiple rows (White 1988).

The caudal segment is the last abdominal segment and represents a fusion of the last three abdominal segments. It bears the posterior spiracles and the anus. Detailed

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terminology of the caudal segment is given by Phillips (1946) and Heppner (1984). The caudal segment can for ease of reference be divided into several areas.

Posterior spiracles occur from the midline to high up on the dorsal edge of the caudal segment and are very useful taxonomic characters. They have been well described by Efflauton (1927), Butt (1937), Phillips (1946) and Exley (1955). Each spiracle usually has three openings or slits, with the exception of *Myopites* spp. which only have two slits (Freidberg 1980). The slits are frequently almost parallel to each other in fruit-infesting species, but are arranged at greater angles to each other in non fruit-infesting species. Spiracles can be flush with the surface or may be set on separate protuberant lobes as in some Terellini larvae. The outer margin of each slit has a supporting sclerotized structure, the rima. Attached to the cuticle at the polar ends of the slits are the spiracular hairs, also known as interspiracular processes (Phillips 1946; Exley 1955). There are usually four bundles of varying numbers of hairs associated with each spiracle. There are more branches to these spiracular hairs in fruit-infesting species than in flower-head feeding or gall-inducing larvae. The ecdysial scar or button (Exley 1955) marks the position of the external openings of the spiracles of the previous instar.

The anal elevation surrounds the anal opening which in fruit-infesting larvae is often flanked by two large anal lobes. Each lobe may be entire, grooved or bilobed and is usually surrounded by several discontinuous rows of spinules often concentrated into a small patch of slightly larger spinules just below the anal opening. In known gall-inducing larvae the anal lobes are absent but the anal opening may be surrounded by small knob-like projections.

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1.3.3 Puparium: Diptera have either obtect pupae, in which the head appendages, wings and legs are visible and lie in sheaths attached to the surface of the body, or exarate pupae, in which these appendages are free. However, exarate pupae are almost always encapsulated within a puparium which is the hardened skin of the last larval instar. Exarate pupae, and puparia, are characteristic features of the suborder Cyclorrhapha, which includes the Tephritidae.

Tephritid puparia range in colour from white through to black. A black puparium in a species that normally has pale coloured puparia, is generally indicative of parasitism by Hymenoptera. Puparia tend to be rounded at the anterior end, have slightly curved lateral, dorsal and ventral surfaces, sometimes with distinct segmentation, and the posterior end may be rounded or flat. The number of tubules in each anterior spiracle and the shape of the posterior spiracles of the third instar larva can sometimes be determined by examination of the puparium. The cephalopharyngeal skeleton of the third instar larva may also be removed from the puparium for examination. However, separation of the many species that may be associated with a particular fruit is seldom possible using the limited set of larval characters obtainable from a puparium. Most frugivorous species spend only a few days as a puparium. It is thus better to wait for the emergence of adults before attempting specific identification. Flower associated species can sometimes be identified from puparia, because colour and spiracle form is often sufficient to separate the small number of species that may attack a given host plant. Some keys have been developed for this purpose (White 1988).

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1.4 THE MEDITERRANEAN FRUIT FLY

1.4.1 Pest status and host range: The Mediterranean fruit fly, *C. capitata,* is considered to be the world's most important, widespread and destructive pest in the entire family Tephritidae (Phillips 1946). Efflauton (1927) gives its distribution range as Continental Africa, India, Australia, New Zealand, East Indies, Bermuda, Azores, South America, Cape Verde Islands, Madeira, Hawaii and southern Europe. In the early 1920's an infestation occurred in Florida, but this was quickly checked (Phillips 1946). It is a highly polyphagous species and has been recorded from wild hosts belonging to a large number of plant families, including Anacardiaceae, Chrysobalanaceae, Cucurbitaceae, Ebenaceae, Loganiaceae, Malpighiaceae, Meliaceae, Oleaceae, Podocarpaceae, Rosaceae, Rubiaceae, Rutaceae, Sapotaceae and Solanaceae. Some preferred commercial hosts include apple, apricot, citrus, cherry, mango, pear, plum, rose apple, and guava. The exact economic losses caused by this pest varies in countries where it occurs.

C. capitata has been recorded from the following hosts in Southern Africa: apple (*Malus domestica*), apricot (*Prunus armeniaca*), peach (*Prunus persica*), blue passion fruit (*Passiflora caerulea*), coffee (*Coffea* sp.), common guava (*Psidium guajava*), fig (*Ficus* sp.), litchee (*Litchi chinensis*), mango (*Mangifera indica*), mulberry (*Morus* sp.), navel and valencia oranges (*Citrus sinensis*), pear (*Pyrus communis*), plum (*Prunus domestica*), quince (*Cydonia oblonga*), grape (*Vitis vinifera*), and youngberry (believed to be *Rubus flagellaris x R. loganobaccus*) (Clausen *et al.* 1965; Annecke & Moran 1982; Hancock

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1987). The garden ornamental plum (*Harpephyllum caffrum*) is also attacked in southern Africa, and it may act as a reservoir host for pest populations (Willers 1979).

C. capitata has been reared from a red asparagus berry (Bezzi 1924), but there was no confirmation that it was garden asparagus (*Asparagus officinalis*), although some workers may have assumed that to be the case. Larvae have also been reared in cherry (*Prunus* sp.) imported from Cyprus into the United Kingdom

Recent work has shown that, at least up to harvesting stage, banana (*Musa x paradisiaca*) and avocado varieties grown in Hawaii are not attacked. Similarly, some varieties of lemon have been shown to be unsuitable as hosts (Spitler *et al.* 1984). Some recorded hosts are only attacked when already damaged, namely avocado, banana (*Musa* sp.), lemon, papaya, and pomegranate.

1.4.2 Description of the adult: The adult males of the Medfly are easily separated from all other members of the family by the black pointed expansion at the apex of the anterior or orbital setae. The females can be separated from other species by the characteristic yellow wing pattern and the apical half of the scutellum which is entirely black (White & Elson-Harris 1992). The mouthparts are small, initially reddish-brown and later almost black (Myburgh *et al.* 1986). The adult Medfly is usually smaller than the housefly and is approximately 3.5-5.0 mm long. It is yellowish with a brown tinge, especially on the abdomen and legs, with some orange and dark patches on the wings. The eyes are predominantly bright metallic blue, but become blackish within 24 hours of death. The thorax is creamy white to yellow with a characteristic pattern of black blotches. The abdomen has two narrow transverse silvery-white bands.

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1.4.3 Life history: The adult females attack ripe or ripening fruit by piercing the soft skin and laying three to fourteen eggs in the puncture. After about three days at 25°C, the eggs hatch into larvae (maggots), which feed inside the fruit pulp and quickly turn the fruit into a rotten mass. Generally, the fruit spoils and drops to the ground. The fully developed larvae leave the fruit, burrow into the soil, change into pupae and emerge from the soil as adult flies. Development from larva to adult takes from 7 to 12 days, depending mainly on the diet and temperature during development. Adult female flies may live up to 40 days and can lay an average of 300 eggs. One complete Medfly life cycle, from egg to egg, takes about three weeks to three months depending on the environmental factors, temperature especially being the determinant factor.

1.4.4 Economic Importance: The Mediterranean fruit fly exploits an extensive range of cultivated and wild host plants. Thin-skinned, ripe, succulent fruits are preferred. Myburgh *et al.* (1986) pointed out that infestation occurred on all deciduous fruits, including grapes, as well as a range of subtropical fruits. Its presence has had serious phytosanitary implications in so far as it negatively impacts on international trade, adding to the costs resulting from stringent phytosanitary requirements.

Feeding by fruit flies produces mushy areas and permits secondary fungal and bacterial infections. Infestation can also result in extensive fruit drop, reducing yield. Many countries have established stringent quarantine procedures against the Medfly and will not permit importation of products from infested areas. Medfly infestations in the United States (US) have been due to importation of infested fruits (Klassen 1989). Therefore, to maintain

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the export of susceptible products to the US, pest free zones of *C. capitata* must be established in exporting countries.

1.5 THE NATAL FRUIT FLY

1.5.1 Pest status and host range: The Natal fruit fly, *C. rosa*, is an African species, originally occuring in areas with warm, humid summers such as KwaZulu-Natal and Mpumalanga. In some areas of South Africa, the bug tree (*Solanum auriculatum*), which was introduced from South America, provides a host for the first spring generation before cultivated fruits become available (Ripley & Hepburn 1930). An adventive population in Reunion was also recorded from the bug tree (Etienne 1972), but it did not attack this plant in Mauritius (Orian & Moutia 1960). *C. rosa* has also been recorded from wild species of Cecropiceae, Euphorbiaceae, Flacourticeae, Loganiaceae, Myrtaceae, Podocarpoceae, Rubiaceae, Rutaceae and Sapotaceae (Munro 1926, 1935; Weems 1966; Hancock 1987).

C. rosa has now extended its range to many other parts of South Africa, including coastal areas further south, and to some Indian Ocean islands where it largely displaces *C. capitata*. Despite the fact that *C. rosa* is not as widespread as *C. capitata*, it is also a major pest. Hancock (1987) has recorded *C. rosa* from the following commercial hosts in Zimbabwe: apple (*Malus domestica*), common guava (*Psidium guajava*), mango (*Mangifera indica*), papaya (*Carica papaya*), plum (*Prunus domestica*), peach (*Prunus persica*), pear (*Pyrus communis*), quince (*Cydonia oblonga*), tomato (*Lycopersicon esculentum*) and grape (*Vitis vinifera*).

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In South Africa it damages apricot (*Prunus armeniaca*), avocado (*Persea americana*), common fig (*Ficus carica*), common guava *(Psidium guajava)*, litchi (*Litchi chinensis*), mango *(Mangifera indica)*, navel and valencia oranges (*Citrus sinensis*), papaya (*Carica papaya*), pear (*Pyrus communis*), plum (*Prunus domestica*) and peach (*Prunus persica*) (Annecke & Moran 1982). In Kenya, *C. rosa* is almost as common a pest of arabica coffee (*Coffea arabica*) as *C. capitata*. It has also been recorded from Natal plum (*Carissa macrocarpa*) (Clausen *et al*. 1965). In the early 1950's *C. rosa* became established in Mauritius, and by the late 1950's it had become a serious pest, attacking a wide range of hosts (Orian & Moutia 1960). Myburgh (1956) elaborated on the historical details of the incidence of *C. rosa* and *C. capitata* in South Africa. However, the importance of these fruit flies has increased as the fruit industry has developed in South Africa.

C. rosa does not rank as high as *C. capitata* in world importance as a fruit pest. As a result there has not been much work done on this species. However, *C. rosa* has the potential of becoming a serious pest.

1.5.2 Description of the adult: The eggs, larvae and pupae of *C. rosa* are superficially similar to those of the Medfly. The adult is about 6 mm long with a wingspan of 10 mm, and is darker in appearance than the Medfly. The eyes are predominantly metallic green. The thorax is dorsally greyish-brown with small black and white patches posteriorly and a white patch on each side. The abdomen is brown with dark transverse bands. The wings are clear with mottled dark patches. The legs are relatively long and males have black feathery bristles on the tibiae of the mesothoracic legs. The adults are

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recognised by a characteristic pattern of brown wing bands and the three black areas in the apical half of the scutellum, as well as the feathering on the mid-tibia of the male, with a lack of feathering on the mid-femur. At present there are no means by which the eggs and larvae of *C. rosa* can be distinguished from those of *C. capitata* (Nel 1983; White & Elson-Harris 1992).

1.5.3 Life History and Economic Importance: The damage caused and seasonal patterns of infestation by the Natal fruit fly are essentially similar to that of the Medfly.

1.6 MOTIVATION FOR THE STUDY

Tephritids are pests in almost all fruit growing areas of the world and their economic importance can be summarized as follows :

- They attack commercially produced fruit;
- Some species have become widespread and are pests in regions far beyond their native range;
- Quarantine restrictions have to be imposed to limit further spread of fruit fly pests;
- Quarantine regulations imposed by an importing country can either deny a producing country a potential export market, or force the fruit exporters to carry out expensive disinfestation treatment.

Monetary estimates of fruit production and fruit fly damage are not available for most countries (White & Elson-Harris 1992). In the Western Cape Province of South Africa, the two fruit fly species, *C. capitata* and *C. rosa*, are major pests in the deciduous fruit industry. The annual cost to control them amounts to R17 million in the Western Cape

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alone, whilst crop losses due to these insects account for a further R7 million (Barnes, pers. comm.). At present a number of fruit fly control programmes are based on the use of pesticides. This has many disadvantages including consumer resistance, which can also lead to loss of markets. This is not the case with the sterile insect technique (SIT), making it an attractive alternative. The use of SIT for pest control is species-specific. Therefore, knowledge of the species composition of fruit flies attacking deciduous fruit in the Western Cape Province is vital for the implementation of a successful SIT programme in this region.

In this study two major aspects, namely identification and some aspects of the field biology of the Mediterranean fruit fly, *C. capitata*, and Natal fruit fly, *C. rosa*, are investigated. The emphasis is on larval identification rather than of eggs and pupae, as the larvae are the stage most frequently encountered in fruit. Means of identification of these fruit fly species in the adult stage have been described elsewhere (Nel 1983; Myburgh *et al*. 1986; White & Elson-Harris 1992).

Larval metamorphosis of *C. rosa* and *C. capitata* is similar, consisting of two moults producing three instars (Myburgh 1956). The present study will involve detailed examination of all three instars of these two species. The sclerotized cephalopharyngeal skeleton, consisting of mouthhooks, hypostomium and pharyngeal skeleton, are the reference structures on which identification of trypetid larvae is based (Phillips 1946).

For this study mouthhooks of all instars for each species were examined, and their sizes and shapes compared using light microscopy. Presence, size and shape of both the anterior and posterior spiracles were investigated in all instars of *C. rosa* and *C. capitata*, using light and scanning electron microscopy. An attempt was made to construct

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identification keys based on larval characters to differentiate the three larval instars of the two species.

The second part of this study included specific aspects of the field biology. This was done in the deciduous fruit orchards and wine grape vineyards in the Western Cape Province of South Africa. Sampling was conducted before, during and after harvesting on different wine grape cultivars and the occurrence of *C. capitata* and *C. rosa* larvae in the grape bunches remaining after harvest was investigated. Forced oviposition and survival studies *in vitro* were also conducted. Proportions of occurrence of *C. capitata* and *C. rosa* in various kinds of infested deciduous fruits from different sites were also investigated.

This study is not only of taxonomic importance, but is also essential for quarantine entomologists as it may facilitate rapid identification of fruit flies intercepted with exported fruit produce. In the application of pest control strategies, such as the sterile insect technique (SIT) programmes, data obtained from this study will be very useful since the application of SIT pest control is species-specific (Knipling 1955; Klassen 1989; Dent 1991; Metcalf & Luckmann 1994; Gomes 1997). Therefore, reliable differentiation between *C. capitata* and *C. rosa* in fruit infestation is thus essential.

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CHAPTER 2

A COMPARATIVE STUDY OF THE LARVAL MORPHOLOGY OF THE NATAL FRUIT FLY, *CERATITIS ROSA*, AND THE MEDFLY, *C. CAPITATA* (DIPTERA: TEPHRITIDAE)

2.1 INTRODUCTION

White & Elson-Harris (1992) reported that of the 65 *Ceratitis* MacLeay species found in tropical and southern Africa, immatures of only nine species have been described. This indicates that very little attention has been given to the morphological description of immature stages, particularly that of larval forms. White & Elson-Harris (1992) gave partial descriptions of the third larval instars of a few species belonging to the genus *Ceratitis*. More recent work on larval Tephritidae is known through the contributions of Munro (1964), Malan & Giliomee (1969), Heppner (1984) and Carroll & Wharton (1989).

Many of the descriptions of larval Tephritidae provided to date are scanty, incomplete and inaccurate. This is evident in the work of Phillips (1946) and White & Elson-Harris (1992), where only partial descriptions of the third instar larvae are given, with no descriptions of either the first or second instar larvae. In addition, the figures presented by Phillips (1946) are not drawn to scale, and are therefore not suitable for comparative studies. In spite of these shortcomings, their contributions have prepared the way for current and future studies of larval Tephritidae.

Although larval identification of *C. rosa* has been of long-standing interest and concern (White & Elson-Harris 1992), no published information on the immature stages of this species is available. In this chapter a description of all the larval instars of *C. capitata* and *C. rosa*, an identification key and characters of possible taxonomic use are provided.

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This is of vital importance for identifying larvae of *C. capitata* and *C. rosa* collected from infested fruits occurring in the field (Chapter 3), and for determining the level of survival of these two fruit flies in different wine grape cultivars (Chapter 4).

2.2 MATERIAL AND METHODS

Laboratory-reared larvae of *C. capitata* and *C. rosa* were obtained from Infruitec-Nietvoorbij (Stellenbosch) of the Agricultural Research Council (ARC) of South Africa. The laboratory colony was initiated from field-collected specimens of *C. capitata* and *C. rosa* obtained in the Western Cape Province. The colony was reared in the INFRUITEC laboratory since 1997 and field material is added to it every year. Additional material (*C. rosa* larvae) was obtained from a fruit fly rearing laboratory at Citrus Research International (CRI) in Nelspruit, Mpumalanga.

For the collection of first instar larvae, eggs were transferred onto moistened filter paper in Petri dishes, and incubated at 25-26°C and approximately 70% relative humidity. The dishes were monitored daily for egg hatch. The first larval emergence took place after an average period of three days. Second and third instar larval collections were made by placing egg-coated filter paper on the rearing medium as described by Barnes (1976), with the eggs directly in contact with medium. The medium was examined daily and the presence of exuviae was used as confirmation that the larvae had moulted to the following stage (instar).

Larval specimens were washed thoroughly in cold water and then killed by immersion in hot water (±60°C). All specimens were preserved in 70% ethanol in small excavated blocks, each block containing a particular instar. Larvae to be slide-mounted

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were slit longitudinally, left overnight in cold 10% potassium hydroxide (KOH) solution, and cleaned by removing the muscular tissue and other body contents with an insect pin.

Additional material for illustration of the cephalopharyngeal skeleton was dissected out and mounted in Hoyer's mounting medium. The dissected material was spread out with the dorsal surface uppermost.

Preserved specimens were used for scanning electron microscopy (SEM) following the method of Grodowitz *et al.* (1982). The larvae were rinsed thoroughly in distilled water to which a drop of liquid soap was added. They were then dehydrated by placing them in 70, 80, 95% and three changes of absolute ethanol for 15 minutes in each solution. The individual larval specimens were mounted with double-sided tape on aluminium stubs and sputter-coated with gold. They were then examined by JEOL-JSM 6100 scanning electron microscope, using an accelerating voltage of 7.0 kV.

The following measurements were made on preserved, unmounted specimens: total body length and width at the sixth abdominal segment (excluding creeping welts) of the first, second and third instars. These measurements were made using a calibrated ocular micrometer attached to a Nikon dissection microscope. Measurements of the cephalopharyngeal skeleton were recorded from slide-mounted material using the Kontron VIDAS image analysis system. The measurements included greatest length of the mandible (from dorsal to ventral knob); height of base of the mandible (from dorsal to ventral knob) and distance from tip of mandible to notch of the tentoropharyngeal sclerite between dorsal and ventral cornuae (CPS). The terminology used in this study follows Teskey (1981).

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2.3 RESULTS :

Table 2.1 Measurements (mm) of various morphological features from laboratory-reared *Ceratitis rosa* (Karsch) larval populations.

Structure	Instar	Mean	Range	Growth Ratio	Sample Size	Variance
Body Length	1	1.98	1.45 - 2.65		31	0.0123
	2	4.27	3.94 - 4.51	2.1	31	0.0121
	3	7.97	7.25 - 8.81	1.9	31	0.0127
Body Width	1	0.33	0.11 - 0.52		31	0.0072
	2	1.02	0.84 - 1.18	3.1	31	0.0072
	3	1.89	1.78 - 2.11	1.9	31	0.0072
Mandible Base	1	0.058	0.055 - 0.062		31	0.0002
	2	0.108	0.097 - 0.116	1.9	31	0.0015
	3	0.149	0.136 - 0.166	1.4	31	0.0003
Mandible Length	1	0.043	0.036 - 0.051		31	0.0006
	2	0.141	0.134 - 0.149	3.3	31	0.0005
	3	0.256	0.229 - 0.275	1.8	31	0.0006
Cephalopharyngeal skeleton (tip to notch)	1	0.151	0.141 - 0.169		31	0.0002
	2	0.351	0.321 - 0.369	2.2	31	0.0004
	3	0.662	0.611 - 0.719	2	31	0.0003

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Table 2.2 Measurements (mm) of various morphological features from laboratory-reared *Ceratitis capitata* (Wiedemann) larval populations.

Structure	Instar	Mean	Range	Growth Ratio	Sample Size	Variance
Body Length	1	1.957	1.78 - 2.17		31	0.0958
	2	3.979	3.28 - 4.22	2	31	0.0689
	3	7.497	6.78 - 8.48	1.9	31	0.0845
Body Width	1	0.312	0.28 - 0.37		31	0.0007
	2	0.793	0.70 - 0.87	2.5	31	0.0009
	3	1.674	1.41 - 1.90	2.2	31	0.0008
Mandible Base	1	0.038	0.029 - 0.047		31	0.0004
	2	0.077	0.065 - 0.087	2.1	31	0.0004
	3	0.135	0.123 - 0.151	2	31	0.0004
Mandible Length	1	0.041	0.035 - 0.051		31	0.0004
	2	0.111	0.101 - 0.117	2.6	31	0.0006
	3	0.203	0.184 - 0.231	1.9	31	0.0059
Cephalopharyngeal skeleton (tip to notch)	1	0.141	0.128 - 0.153		31	0.0018
	2	0.293	0.265 - 0.316	2.2	31	0.0022
	3	0.541	0.449 - 0.573	2	31	0.0022

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2.3.1 Description of larval instars of *Ceratitis rosa* Karsch

2.3.1.1 First instar : Larvae very small (Table 2.1); cuticle transparent allowing a clear view of the cephalopharyngeal skeleton using phase contrast; metapneustic.

Cephalopharyngeal skeleton with mandible (Fig. 2.1) weakly sclerotized, stout subapical tooth, shorter and slightly broader than apical tooth.

Posterior spiracles (Fig. 2.2) with two slit-like openings (third or ventral opening of subsequent instars absent). Spiracular hairs about twice as long as rima, arranged in four groups as in later instars.

2.3.1.2 Second instar : Larvae small-sized (Table 2.1); cuticle transparent with shape similar to that of the third instar.

Anterior spiracles (Fig. 2.3) present on the dorsolateral part of the first thoracic segment, and a pair of posterior spiracles present on the last abdominal segment; amphipneustic. Anterior spiracles slightly evaginated from the surface of the segment resembling an oval-ovoid shape; row of minutely perforated finger-like processes or spiracular tubules present on the external edge; number of spiracular tubules ranging from 10-12 (av.11).

Cephalopharyngeal skeleton (Fig. 2.4) well-sclerotized; mandible with sub-apical tooth approximately half the length of the apical tooth.

Oral ridges (Fig. 2.5) with an average of eight rows of short, bluntly rounded teeth.

Posterior spiracles (Fig. 2.6) with three slit-like openings, approximately 3-3.5 times longer than wide; dorsal and ventral spiracular hair bundles of about five hairs.

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2.3.1.3 Third instar : Larvae medium-sized (Table 2.1); creamish-white to yellow in colour, elongate, sub-cylindrical and gradually tapering anteriorly; amphipneustic.

Anterior spiracles (Fig. 2.7a, b) medium-sized, with spiracular tubules as in second instar; 11-13 tubules (av. 11).

Cephalopharyngeal skeleton (Fig. 2.8) black, heavily-sclerotized; mandible with small, reduced, ventrally pointed, well-sclerotized sub-apical tooth.

Oral ridges (Fig. 2.9) with 11-13 rows of well-developed, bluntly rounded teeth; 2-3 rows of pre-oral lobes present.

Posterior spiracles (Fig. 2.10) occurring just above the dorsal midline, with three slit-like openings; rim of each spiracular slit about 3.5-4 times as long as broad; dorsal and ventral spiracular bundles of 12-14 hairs, branched in apical half, lateral bundles with six to eight hairs.

2.3.2 Description of larval instars of *C. capitata* (Wied.)

2.3.2.1 First instar: Larvae extremely small (Table 2.2); cuticle almost translucent; metapneustic.

Cephalopharyngeal skeleton only weakly sclerotized, with mandibles (Fig. 2.11) yellow to pale amber and with the remainder of the skeleton slightly darker; mandibles with sub-apical tooth stout and slightly broader and shorter than the apical.

Posterior spiracles with two slit-like openings (third or ventral opening absent, only evident in the subsequent instars). Spiracular hair bundles almost twice as long as rima, arranged in four groups.

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2.3.2.2 Second instar: Larvae small-sized (Table 2.2); cuticle creamish-white, shape similar to third instar but smaller; amphipneustic.

Anterior spiracles (Fig. 2.12) each with eight to ten tubules. Cephalopharyngeal skeleton (Fig. 2.13) well sclerotized basally, mandible with sub-apical tooth smaller than the apical tooth.

Oral ridges (Fig. 2.14) with approximately eight rows of serrated, rounded teeth. Posterior spiracles with three slit-like openings; openings approximately 2-2.5 times longer than wide; dorsal and ventral spiracular bundles consisting of five hairs each.

2.3.2.3 Third instar: Larvae medium-sized (Table 2.2); cuticle creamish-white, shape subcylindrical, tapering anteriorly; amphipneustic.

Anterior spiracles (Fig. 2.15a, b) with eight to ten tubules. Cephalopharyngeal skeleton (Fig. 2.16) heavily sclerotized; mandible without sub-apical tooth.

Oral ridges (Fig. 2.17) with eight rows of short bluntly rounded teeth. Posterior spiracles with three slit-like openings, each slit about three times longer than wide; dorsal and ventral spiracular bundles of six to nine hairs, branched in apical half, lateral bundles with four to six hairs.

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2.3.3 Identification key to larval instars of *C. capitata* and *C. rosa*

1. Anterior spiracles absent; oral ridges absent; cephalopharyngeal skeleton weakly sclerotized; sub-apical tooth well-developed; posterior spiracles with two small openings.....2

   Anterior spiracles present; oral ridges present; cephalopharyngeal skeleton well-sclerotized basally; sub-apical tooth variable; posterior spiracles with three slit-like openings.....3

2. Mandible base tapering and ventrally flattened below the sub-apical tooth (Fig. 2.1) .....*C. rosa* first instar

   Mandible base ventrally semi-curved below the sub-apical tooth (Fig. 2.11).....*C. capitata* first instar

3. Narrow, elongate felt chambers; approximately 8 rows of oral ridges.....4

   Broad, short felt chambers; more than 8 rows of oral ridges; cephalopharyngeal skeleton heavily sclerotized apically and medially.....5

4. With 8-10 anterior spiracular tubules (Fig. 2.12).....*C. capitata* second instar

   With 10-13 anterior spiracular tubules (Fig. 2.3).....*C. rosa* second instar

5. Sub-apical tooth absent; 8-10 rows of oral ridges; 8-10 rows of anterior spiracular tubules (Figs 2.15a, b; 2.16 & 2.17).....*C. capitata* third instar

   Sub-apical tooth present; maximum of 13 rows of oral ridges; 10-12 rows of anterior spiracular tubules (Figs 2.7a, b; 2.8 & 2.9).....*C. rosa* third instar

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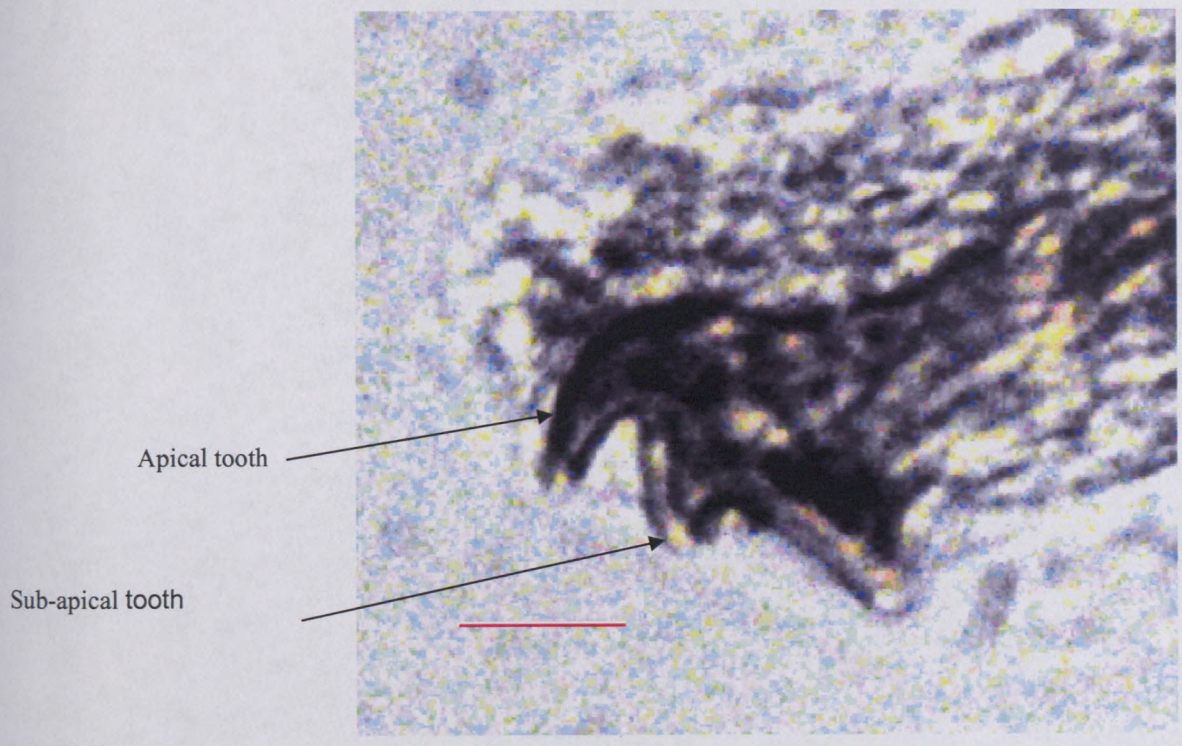

Fig. 2.1 *C. rosa* (first instar): mandible (scale bar = 0.03 mm)

Fig. 2.2 *C. rosa* (first instar): posterior spiracles. (SEM)

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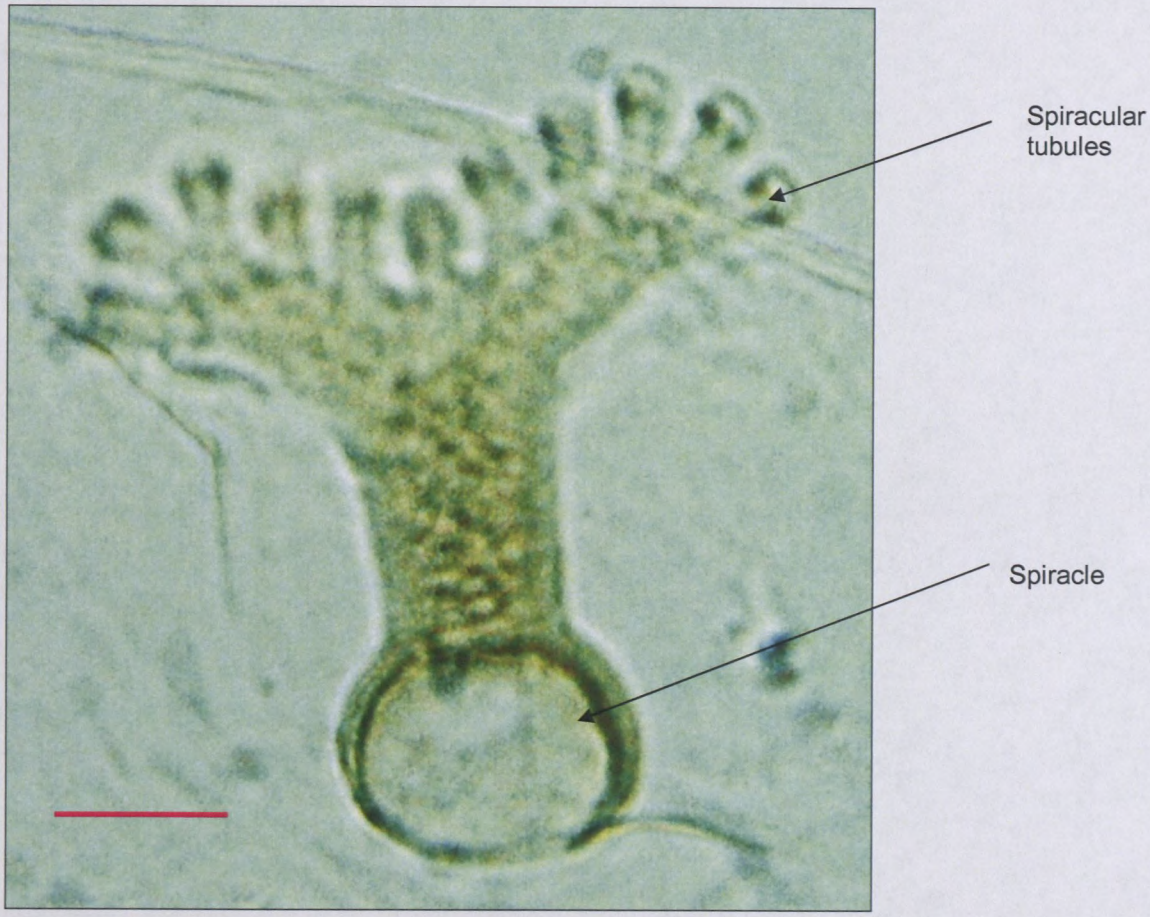

Fig. 2.3 *C. rosa* (second instar): anterior spiracles (scale bar = 0.03 mm)

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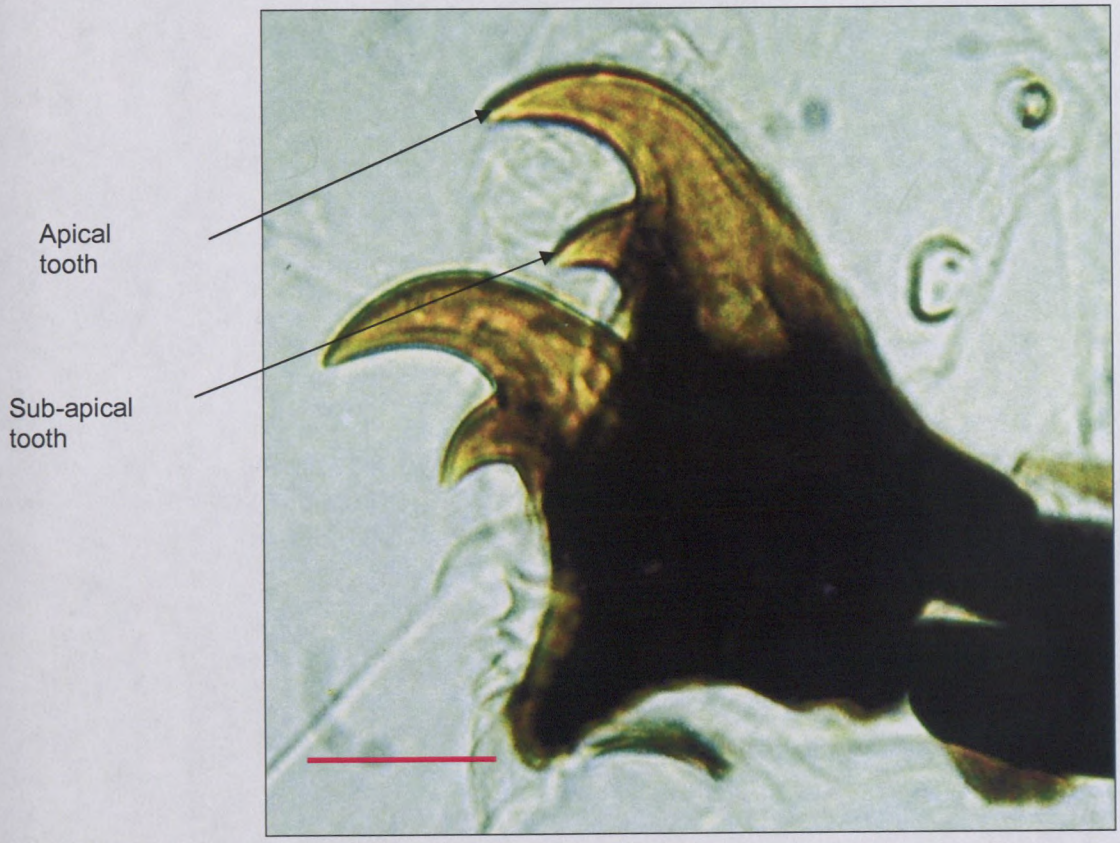

Fig. 2.4 *C. rosa* (second instar): mandible (scale bar = 0.07 mm)

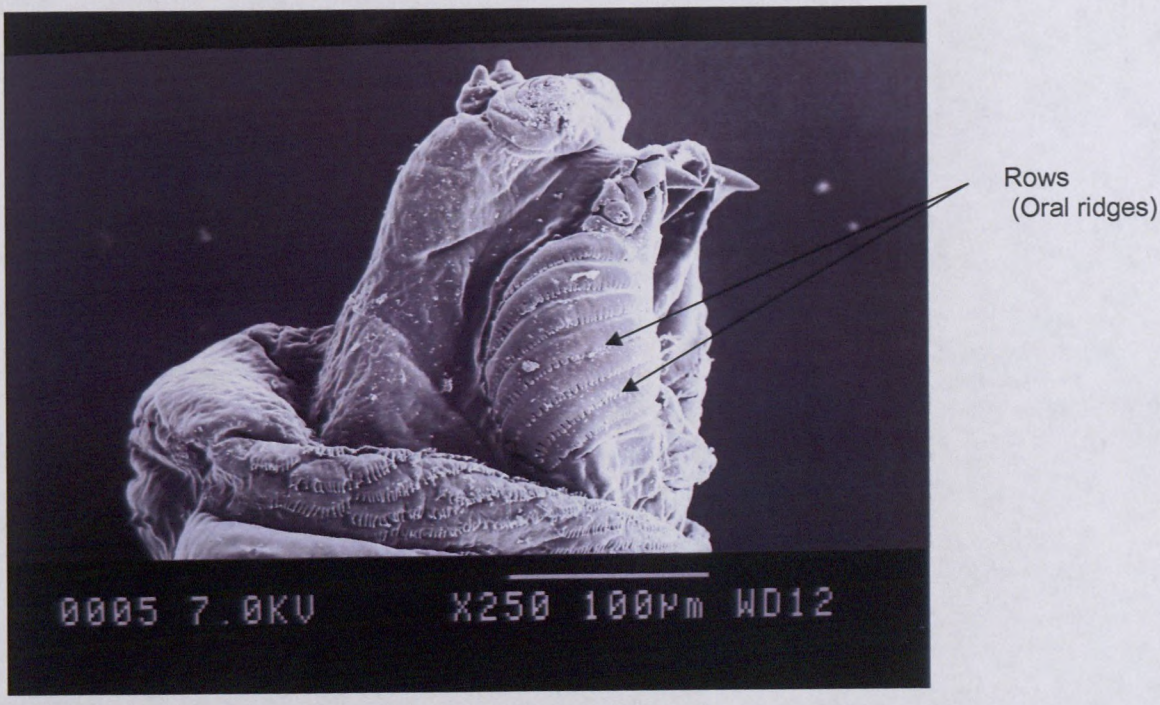

Fig. 2.5 *C. rosa* (second instar): oral ridges

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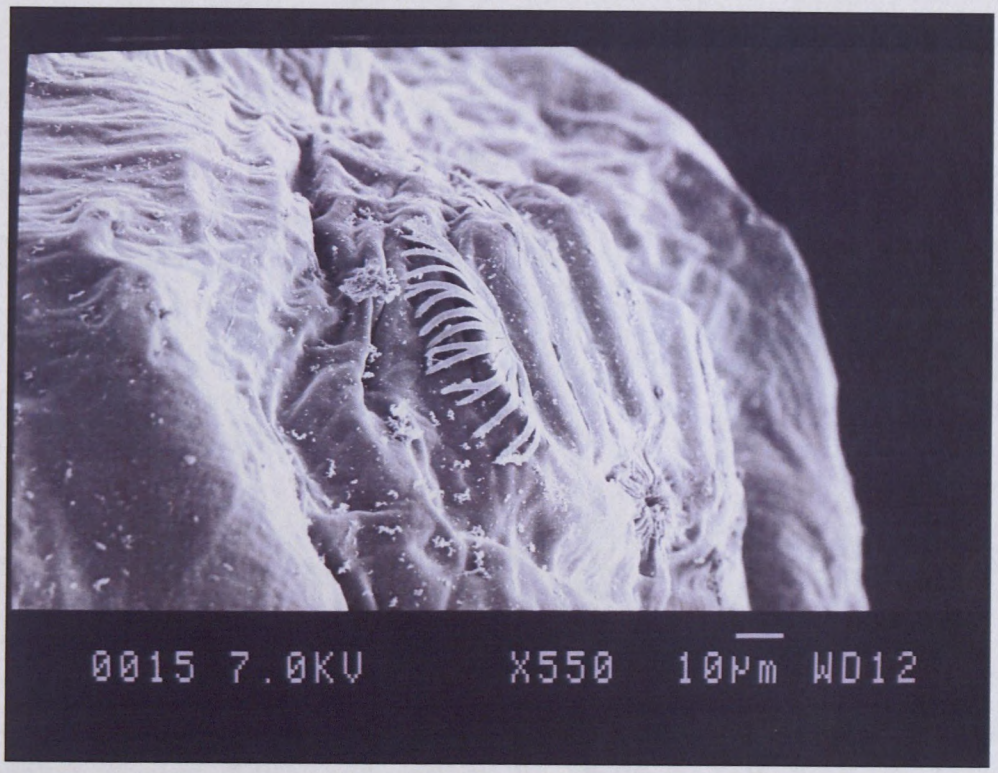

Fig. 2.6 *C. rosa* (second instar): posterior spiracles

Fig. 2.7 a) *C. rosa* (third instar): anterior spiracles (scale bar = 0.3 mm)

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Fig. 2.7 b) SEM of *C. rosa* (third instar): anterior spiracles

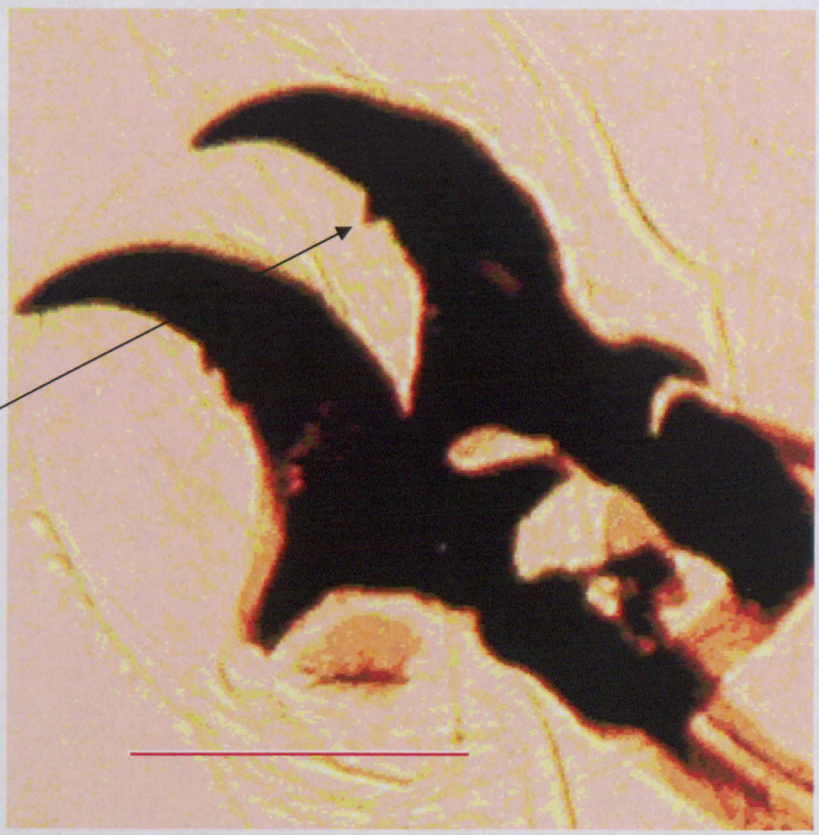

Fig. 2.8 *C. rosa* (third instar): mandible (scale bar = 0.25 mm)

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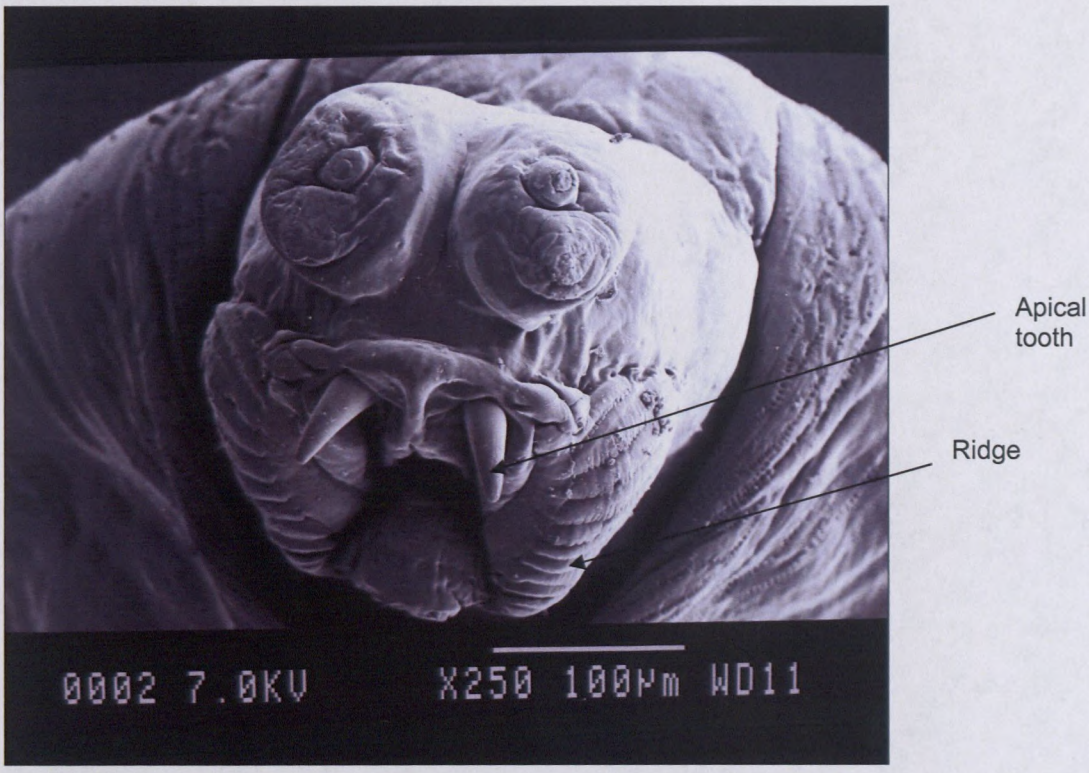

Fig. 2.9 *C. rosa* (third instar): oral ridges

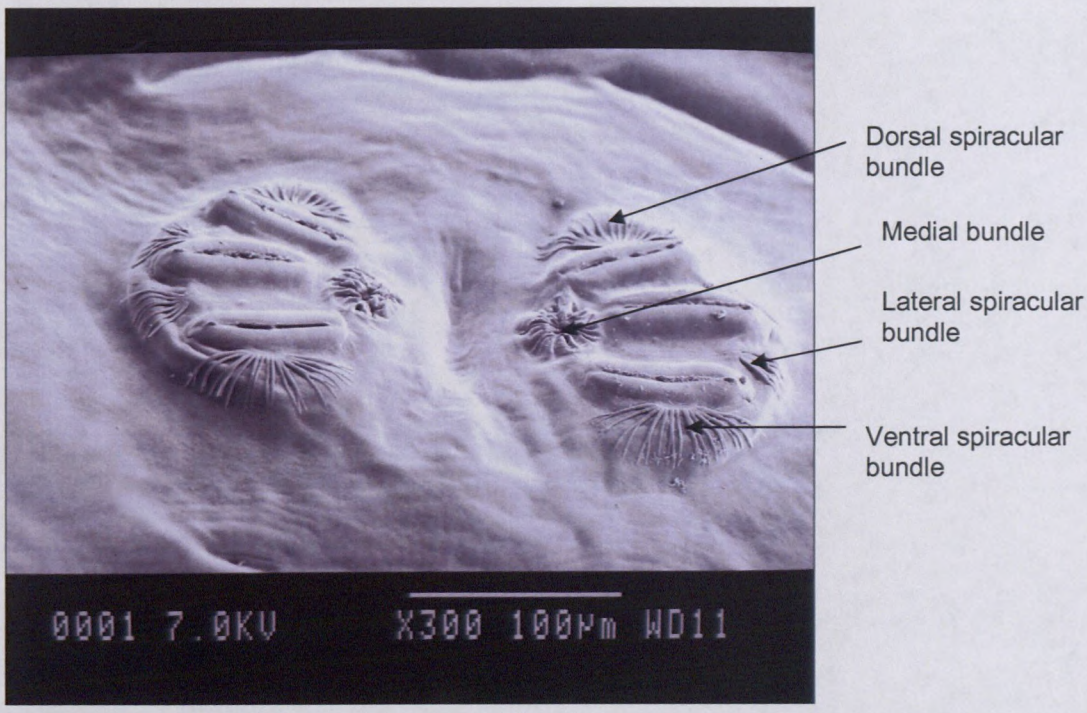

Fig. 2.10 *C. rosa* (third instar): posterior spiracles (SEM)

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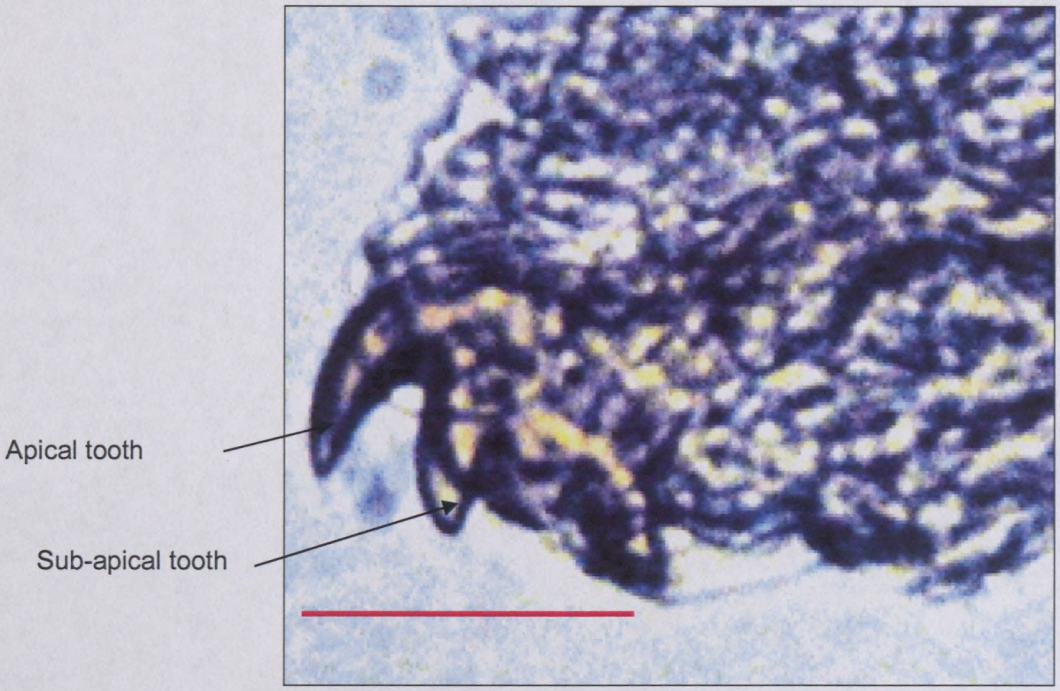

Fig 2.11 *C. capitata* (first instar): mandible (scale bar = 0.04 mm).

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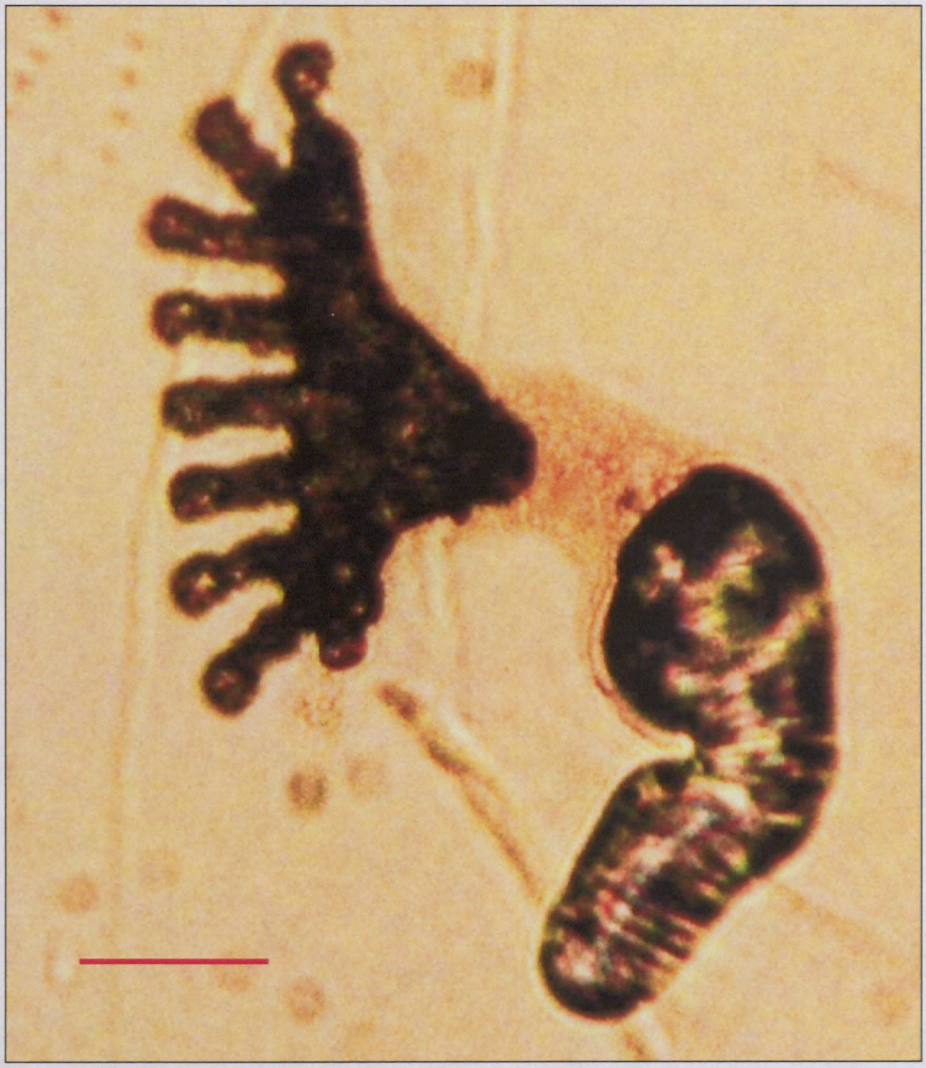

Fig. 2.12 *C. capitata* (second instar): anterior spiracles (scale bar = 0.035 mm)

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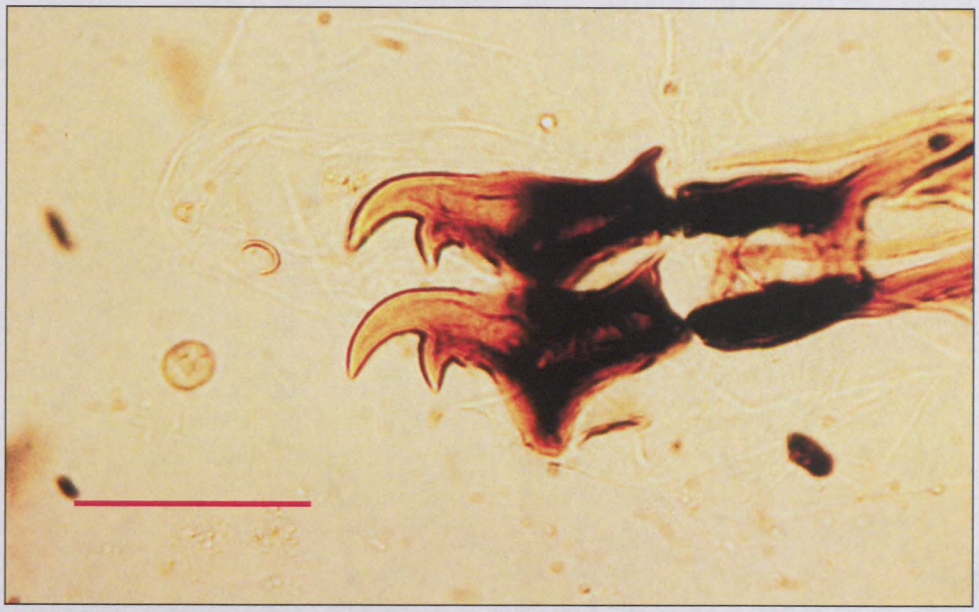

Fig. 2.13 *C. capitata* (second instar): mandible (scale bar = 0.11 mm)

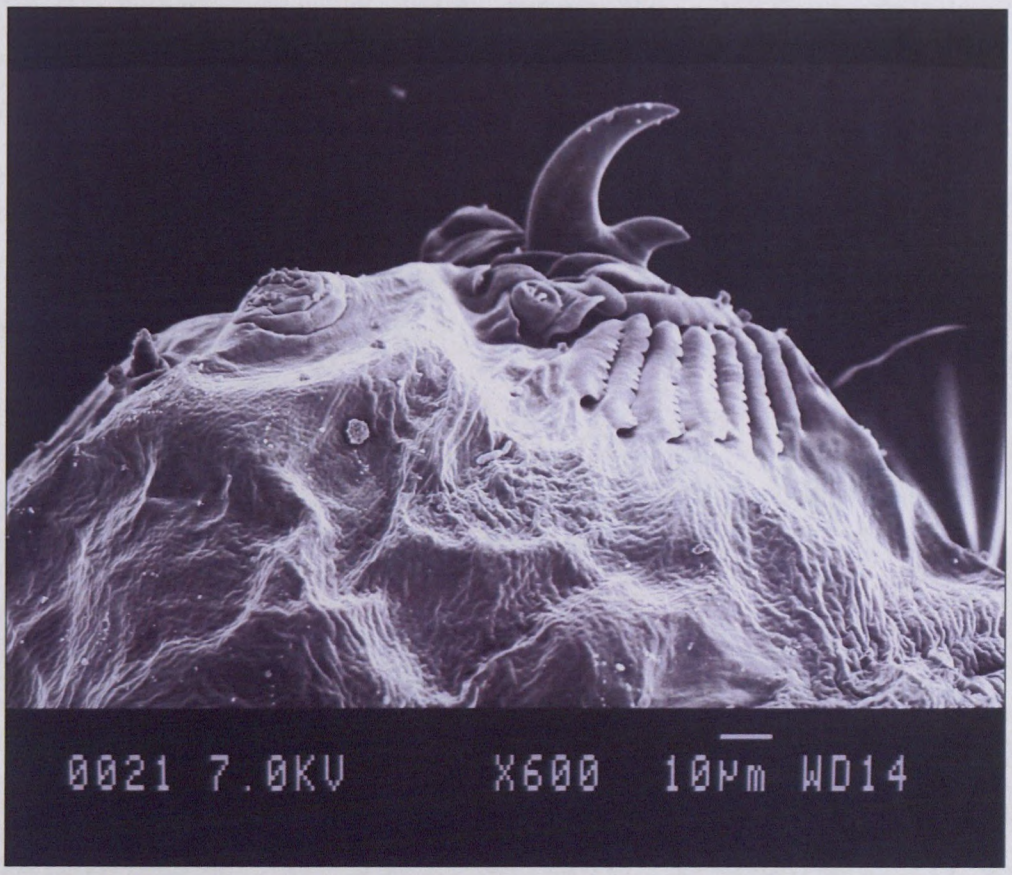

Fig. 2.14 *C. capitata* (second instar): oral ridges

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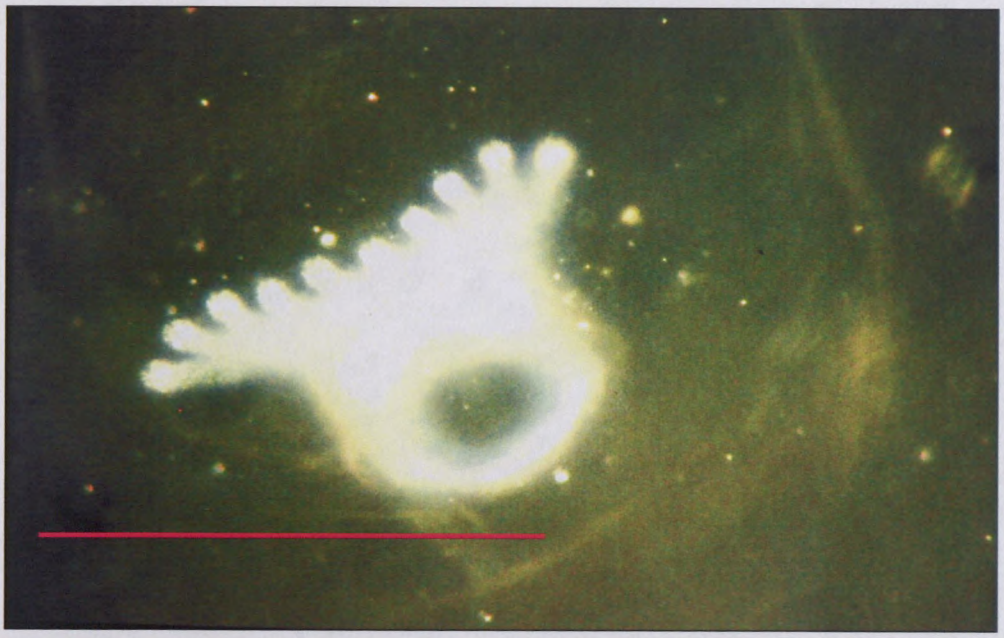

Fig. 2.15 a) *C. capitata* (third instar): anterior spiracles (scale bar = 0.25mm)

Fig. 2.15 b) SEM of *C. capitata* (third instar): anterior spiracles

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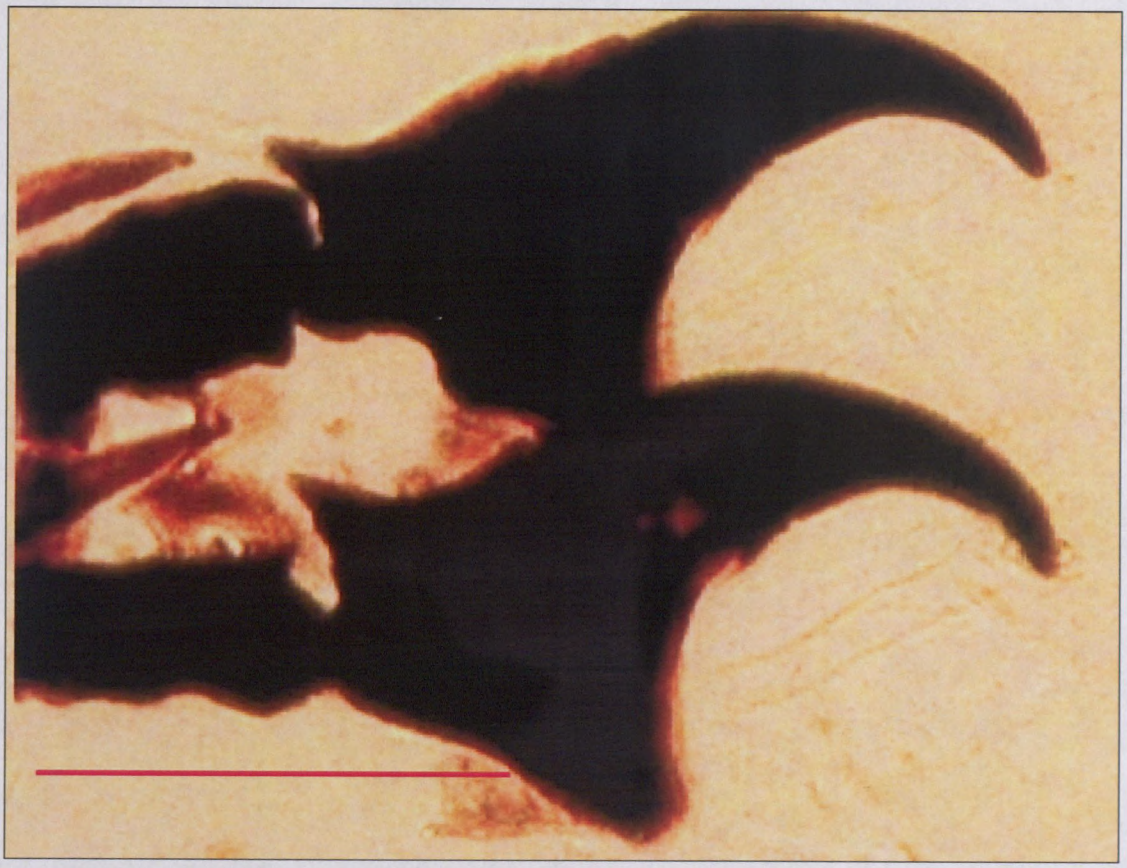

Fig. 2.16 *C. capitata* (third instar): mandible (scale bar = 0.2 mm)

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Fig. 2.17 *C. capitata* (third instar): oral ridges

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2.4 DISCUSSION

White & Elson-Harris (1992) provided a key to the larvae of seven *Ceratitis* species of economic importance. However, these authors also pointed out that this key was largely based on old and inadequate descriptions. A major omission from this key was *C. rosa*, the larvae of which are undescribed, despite being a pest of quarantine importance. A description of *C. capitata* third instar larvae was given by White & Elson-Harris (1992) and by Koen (1998).

Anterior spiracles are absent in the first instar, but present in the second and third instars of both *C. rosa* and *C. capitata*. According to Richards & Davies (1977) first instar larvae of Cyclorrhapha are usually metapneustic. There is no distinct difference in the number of anterior spiracular tubules between the second and third instars of *C. rosa* and *C. capitata*. The majority (approximately 90%) of the second instar *C. rosa* larvae examined, had up to 11 anterior spiracular tubules while the remainder possessed a maximum of 13. This was similar to the third instar larvae, where the number of tubules ranged from 11 to 13. A large proportion (approximately 60%) had 13 tubules. Therefore, there was no convincing evidence that the number of anterior spiracular tubules of *C. rosa* increased from the second to the third instar as suggested by Hennig (1948). In *C. capitata*, the number of anterior spiracular tubules ranged between eight and ten (average of nine) in both second and third instar larvae. Hardy (1949) reported that the number of tubules did not change from second to third instar larvae of *C. capitata* (Wiedemann), *Dacus curcubitae* Coquillet and *D. dorsalis* Hendel, as is the case with *C. rosa*.

Another interesting feature of the anterior spiracles was that in both species studied here the number of tubules differed on both sides of the same specimen. A difference of

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one to two tubules was observed in almost all the specimens examined.

Anterior spiracles of the second instar were longer than wide in both *C. rosa* and *C. capitata*. This was because of the structure of the narrow felt chamber present in the second instar larvae, which resulted in a Y-shaped structure. However, in the third instar the length and width of the anterior spiracles were approximately equal. It was difficult to see this feature (length/width ratio of anterior spiracles) when using the SEM since the spiracular tubules were only slightly evaginated from the surface. However, it was clearly evident using light microscopy on slide-mounted or dissected material.

Posterior spiracles have been characterized by length/width ratio of the slits and the number and degree of branching of the spiracular hairs. In the first instar of both *C. rosa* and *C. capitata* the posterior spiracles had only two openings, whilst the second and third instars had three slit-like openings. The length/width ratios of the slits in the first and second instar larvae were much smaller and there were fewer branches than in the third instar larvae. This agrees with Hardy's (1949) observation on larvae of *Ceratitis*, *Dacus*, *Rhagoletis* and some *Anastrepha* spp. This is probably a general characteristic of fruit-infesting Tephritidae.

Oral ridges were absent in the first instar larvae of *C. rosa*. Hardy (1949) reported that they were also absent in the first instar larvae of *C. capitata*, *D. curcubitae* and *D. dorsalis*. In the second instar larvae, the mean number of oral ridges was eight, whilst 12-14 rows were observed in the third instar larvae of *C. rosa* and *C. capitata*.

First instar larvae of *C. rosa* and *C. capitata* possess few characters which are present and useful for identification. Anterior spiracles and oral ridges are absent and the posterior spiracles are extremely small. Posterior spiracles of the first instar of *C. rosa* and

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C. capitata have only two-rounded spiracular openings, whilst the subsequent instars have three well-defined slit-like openings. However, cephalopharyngeal skeleton characters may be of taxonomic use in the identification of first instar larvae of *C. rosa* and *C. capitata*.

Third instar larvae of *C. rosa* and *C. capitata* possess most of the characters of the second instar. There is less sclerotization of the cephalopharyngeal skeleton in the second than in the third instar larvae. In addition, the second instar larvae have mandibles with stout ventral teeth broader than that of the third instar larvae and with a distinct window. Thus, the presence and number of anterior spiracular tubules, the size and shape of the mouthhooks and oral ridges are characters which may be useful in differentiating between second and third instar larvae of *C. rosa* and *C. capitata*.

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CHAPTER 3

INSTAR SEPARATION BETWEEN LARVAL POPULATIONS OF *CERATITIS CAPITATA* (WIEDEMANN) AND *C. ROSA* (KARSCH) : A MORPHOMETRIC APPROACH

3.1 INTRODUCTION

To identify areas of infestation and to determine the degree of spread of *C. capitata* and *C. rosa* re-infestations, rapid and accurate identification of fruit fly larvae infesting the fruits is required besides other monitoring methods such as adult trapping. Since the use of SIT for pest control is species-specific, the ability to discriminate one species from the other as early as at the larval stage is vital as this stage is responsible for causing direct injury to crops.

The current status of Tephritidae taxonomy relies almost exclusively on adult characters (Ripley *et al.* 1930; Munro 1947, 1964; Weems 1966; Foote 1980; Nel 1983; White & Elson-Harris 1992). However, it is possible to differentiate larval Tephritidae employing morphological criteria (Phillips 1946; Hardy 1949; Exley 1955; Dadour *et al.* 1992; White & Elson-Harris 1992).

In the previous chapter (Chapter 2) of this study the use of morphological features for differentiating between *C. capitata* and *C. rosa* was investigated. Recently, some workers have applied biochemical techniques for identification of fruit fly larvae (Khambhampati *et al.* 1992; Baruffi *et al.* 1994; Haymer *et al.* 1994; Sonvico *et al.* 1996; Sutton & Steck 1996).

This chapter presents a morphometric approach for differentiating between *C. capitata* and *C. rosa* larvae. These fruit fly species have both been reported to have

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three instars (Myburgh 1956). Measurements of various parts of the cephalopharyngeal skeleton and larval body size have been used to determine and differentiate dipteran larval instars (Carrol & Wharton 1989). The most common method is by examination of simple frequency distributions to aid in detecting peaks in a multimodal distribution, each peak representing an instar. This approach assumes that insect growth is discontinuous with major increments in size limited to periodic moults. Once the new cuticle sclerotizes, structural size is assumed to remain constant during any particular instar.

In principle, the technique should present little or no difficulty in instar separation, if there is minimal or no overlap in instar measurements. Growth ratios from one larval instar to the next are often constant as proposed by Dyar's rule (Daly 1985). In this study, finite mixture analysis (Flury & Randal 1995) was used to analyse univariate mixtures of data collected for all three instars of *C. capitata* and *C. rosa*.

3.2 MATERIAL AND METHODS

Laboratory-reared larvae of *C. capitata* and *C. rosa* were obtained from Infruitec-Nietvoorbij, an institute of the Agricultural Research Council (ARC), South Africa. The laboratory colony was initiated in 1997 from field-collected material of *C. capitata* and *C. rosa* obtained in the Western Cape Province, South Africa.

Field-collected larval populations were obtained from infested nectarines (167 specimens for *C. capitata)* in a home garden in the Western Cape Province, and infested guavas (107 specimens for *C. rosa*) from the garden of a university residence in Stellenbosch, Western Cape Province. The infested fruits (guavas and nectarines) were cut at the conspicuous oviposition sites from which larvae of different instars were

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extracted using fine tweezers. Larvae were reared in a carrot powder-sugar-yeast diet (Barnes 1976). The rearing methods and environmental conditions were similar to those described in Chapter 2.

Measurements of different morphological features (body length, body width, cephalopharyngeal skeleton (tip to notch), mandible base and mandible length) were made (Carrol & Wharton 1989). These were used to establish morphometric distinctions between the larvae of *C. rosa* and *C. capitata*. The data were analysed using finite mixture analysis (FMA_N1) (Flury & Randall 1995). This program resolves a multimodal curve of a frequency distribution into its individual Gaussian components and calculates proportions for each component in areas of overlap (Flury & Randall 1995). Finite mixture analysis was set to divide the measurements of each parameter into three groups (instars). It then determined the proportions of individuals in each group, the means of each group and their variances.

3.3 RESULTS AND DISCUSSION

There was an increase in the size of all the structures measured at each successive developmental stage (Tables 2.1, 2.2, 3.1 and 3.2). Measurements of all the structures were larger in the field-collected fruit flies than in the laboratory-reared fruit flies (Tables 2.1 & 2.2 and 3.1 & 3.2). All the structures of larvae of *C. rosa* were larger than those of *C. capitata*. Figures 3.1-3.10 show the frequency distribution histograms of different structures into which different instars of *C. capitata* and *C. rosa* were grouped.

Clear separation between the instars was achieved using cephalopharyngeal skeleton (Figs 3.3a & b; 3.8a & b), mandible length (Figs 3.4a & b; 3.9a & b) and body

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length (Figs 3.1a & b; 3.6a & b). However, for body width (Figs 3.2a & b) and mandible base (Figs 3.5a & b) there was more overlap between the 1st and the 2nd instar than between the 2nd and the 3rd instar, suggesting that more erroneous classifications would be made between the 1st and 2nd than between the 2nd and 3rd instars. Sexual dimorphism may have led to some of the overlapping (Figs 3.2a, 3.3a and 3.5a).

There were significant differences (Levene, $p<0.05$) between the variances of different structures measured (Tables 2.1, 2.2, 3.1 & 3.2) even though a few exceptions were evident. In particular, the variances were greater for field samples (Tables 3.1 & 3.2) than for laboratory samples (Tables 2.1 and 2.2).

The sclerotized mouthparts (mandible base, mandible length and tip to notch of the cephalopharyngeal skeleton) on slide-mounted material showed less variance than the measurements of body dimensions (body length and width).

Food quality appeared to influence larval size and, to some extent, the sclerotized mouth parts since the field specimens were bigger than laboratory-reared specimens in all cases (Tables 2.1, 2.2, 3.1 and 3.2). Schmidt & Lauer (1977) found that nutritional quality influenced the proportions of structures in instar groups of *Choristoneura viridiz* and *C. occidentalis* (Lepidoptera: Tortricidae).

In the laboratory populations, growth ratios between all the instars provided only an approximate conformity to Dyar's rule (Tables 2.1, 2.2, 3.1 and 3.3). Conformation of Dyar's rule and hence, the geometric progression in the field samples, was not applicable to most of the structures measured. However, in both field (Table 3.2) and laboratory-collected (Table 3.1) larvae, body width and mandible length were the two structures that consistently deviated from Dyar's rule in both species, while body length, CPS length and

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mandible base length showed reasonable agreement (Tables 2.1, 2.2, 3.1 and 3.3). Similar discrepancies have been reported for other insects (Schmidt *et al.* 1977; Jobin *et al.* 1992; McClellan & Logan 1994; Fantinou *et al.* 1996). This would imply that Dyar's rule is not always applicable, and consequently continues to be controversial. Daly (1985) even argued that constant geometric relation, in the strict sense, is not a fundamental feature of insect growth.

Schmidt *et al.* (1977) observed that the frequency distribution curves provided clear results when the insects were fairly homogenous with regard to rate of development and number of instars. This is applicable to fruit flies.

Convergence in the finite mixture analysis was achieved for all the structures. However, the variability between the laboratory and field populations in size of all the structures examined implies that size is less useful for distinguishing between instars and species than morphological characters (Chapter 2). Of all the structures used in this study, body length, cephalopharyngeal skeleton (tip to notch) and mandible length are most suitable for differentiating between instars and between species since they showed clear separations with minimal overlaps.

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Table 3.1 Measurements (mm) of various morphological features from field samples of *Ceratitis capitata*.

Structure	Instar	Mean	Range	Growth Ratio	Proportions	Variance
Body Length	1	2.02	1.88 - 2.60		0.245	1.3421
(n = 167)	2	4.21	3.90 - 4.80	2.08	0.264	0.1561
	3	8.73	6.60 - 10.41	2.07	0.491	0.8931
Body Width	1	0.37	0.30 - 0.46		0.235	0.0021
(n = 167)	2	0.87	0.75 - 0.97	2.35	0.274	0.0042
	3	1.73	1.48 - 2.14	2.01	0.491	0.0381
Mandible Base	1	0.042	0.031 - 0.051		0.245	0.0003
(n = 167)	2	0.081	0.073 - 0.092	1.93	0.264	0.0003
	3	0.146	0.121 - 0.152	1.8	0.491	0.0004
Mandible Length	1	0.047	0.037 - 0.054		0.246	0.0004
(n = 167)	2	0.111	0.089 - 0.121	2.36	0.263	0.0004
	3	0.202	0.182 - 0.244	1.82	0.491	0.0004
Cephalopharyngeal	1	0.147	0.131 - 0.162		0.245	0.0004
skeleton (tip to notch)	2	0.297	0.271 - 0.320	2.02	0.264	0.0006
(n = 167)	3	0.555	0.510 - 0.586	1.87	0.491	0.0003

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Table 3.2 Measurements (mm) of various morphological features from the field samples of *Ceratitis rosa.*

Structure	Instar	Mean	Range	Growth Ratio	Proportions	Variance
Body Length	1	2.15	1.50 - 2.70		0.245	0.1962
(n = 107)	2	4.51	3.90 - 4.90	2.1	0.264	0.1209
	3	9.89	7.84 - 10.50	2.19	0.491	0.4966
Body Width	1	0.45	0.24 - 0.60		0.245	0.0139
(n = 107)	2	1.05	0.90 - 1.20	2.36	0.264	0.0139
	3	2.01	1.78 - 2.20	1.9	0.491	0.0139
Mandible Base	1	0.061	0.050 - 0.065		0.245	0.0002
(n = 107)	2	0.111	0.095 - 0.120	1.85	0.264	0.0006
	3	0.159	0.135 - 0.170	1.43	0.491	0.0013
Mandible Length	1	0.046	0.035 - 0.055		0.245	0.0005
(n = 107)	2	0.141	0.124 - 0.152	3.07	0.264	0.0006
	3	0.267	0.215 - 0.280	1.9	0.491	0.0003
Cephalopharyngeal	1	0.161	0.145 - 0.175		0.245	0.0007
skeleton (tip to notch)	2	0.352	0.317 - 0.375	2.19	0.264	0.0003
(n = 107)	3	0.647	0.499 - 0.725	1.84	0.491	0.0004

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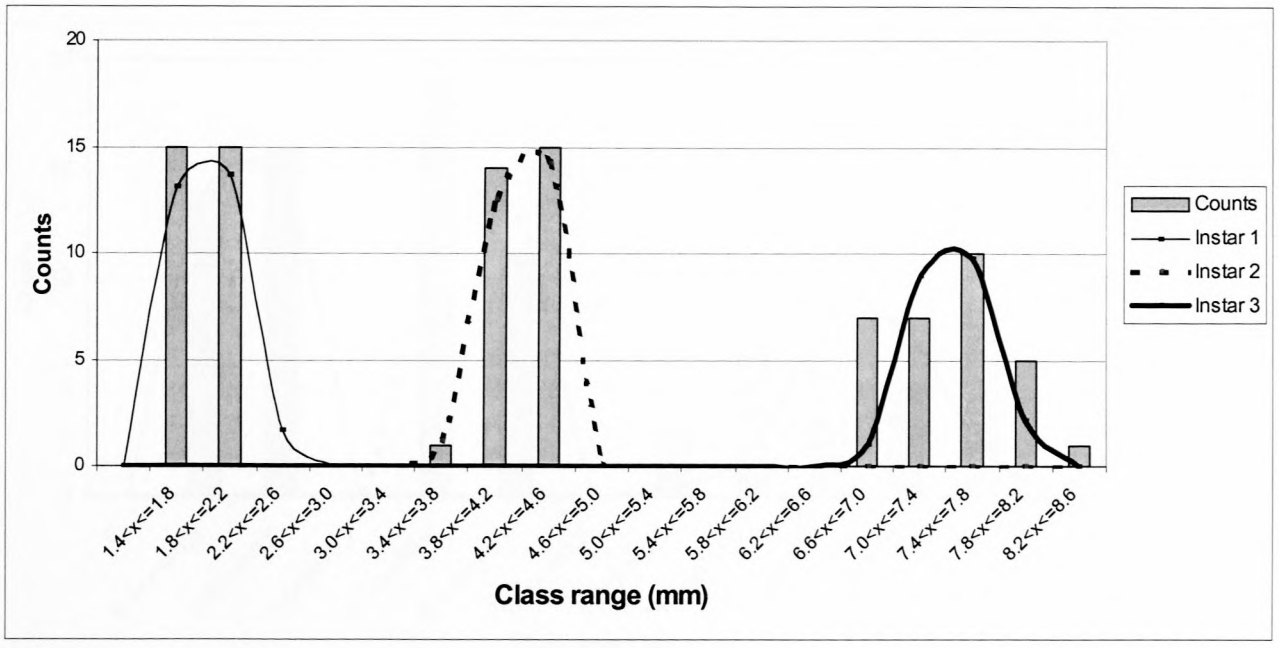
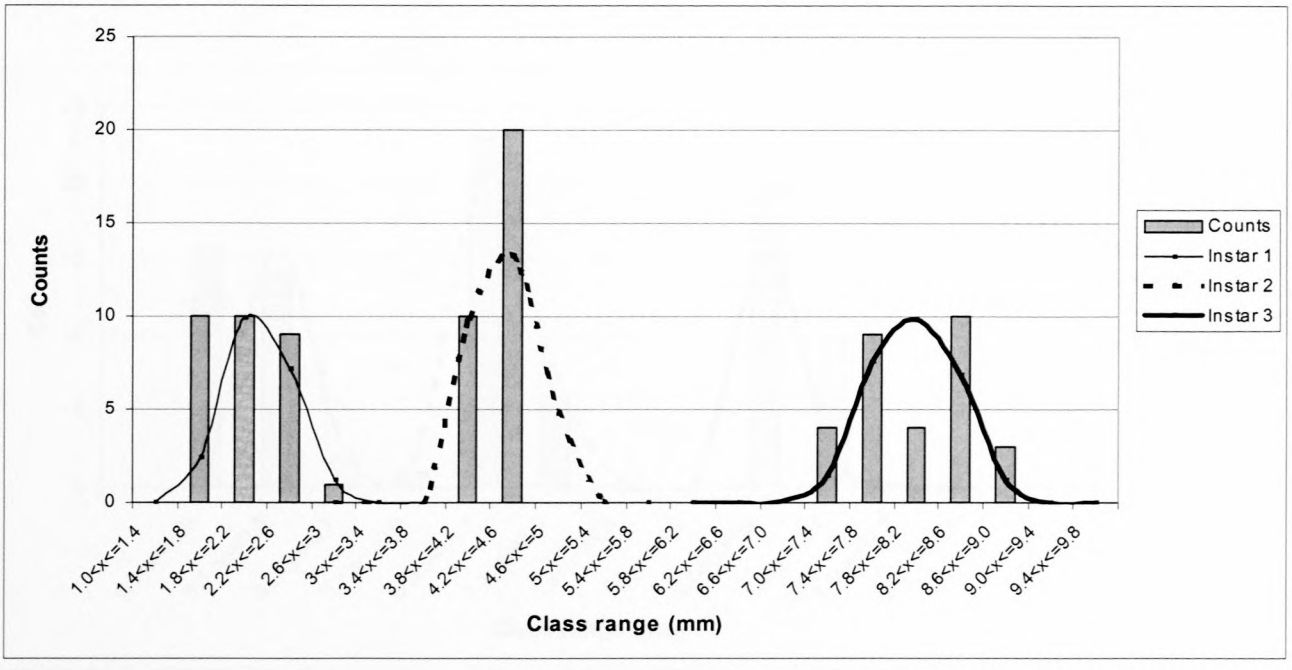


A



B

Fig. 3.1 Frequency distribution of observed length of the body (bars) and the estimated frequency of distribution for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* from a laboratory population.

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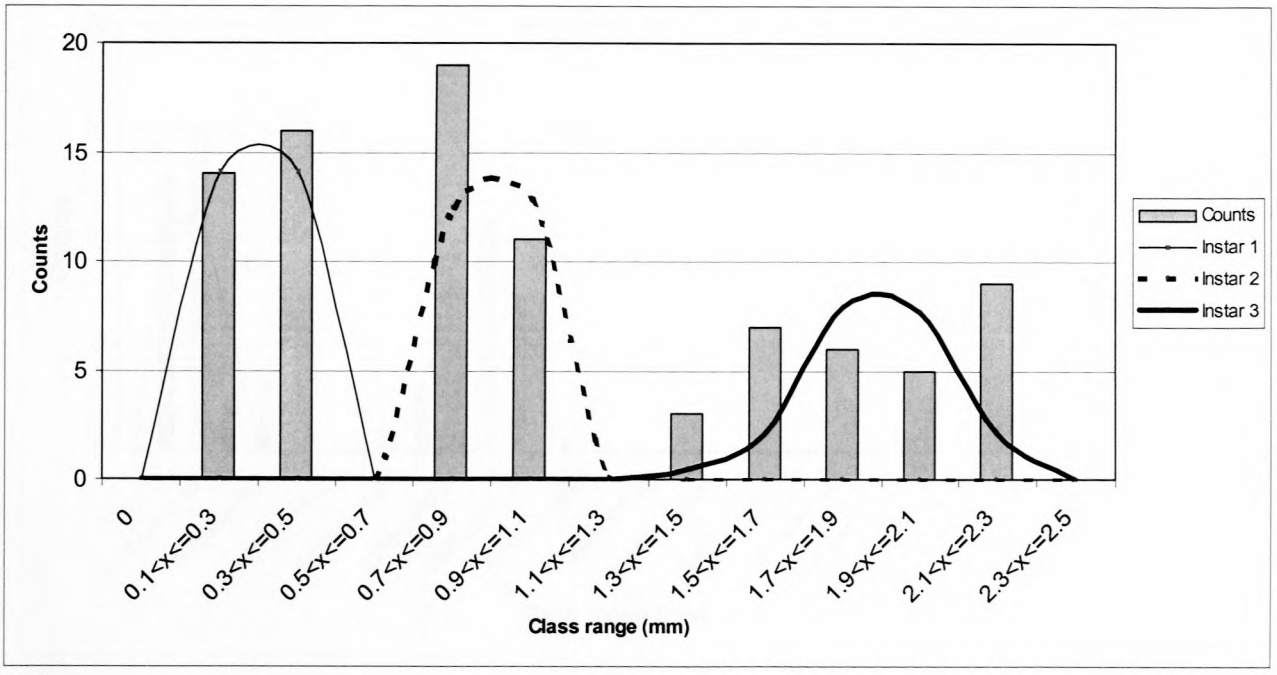
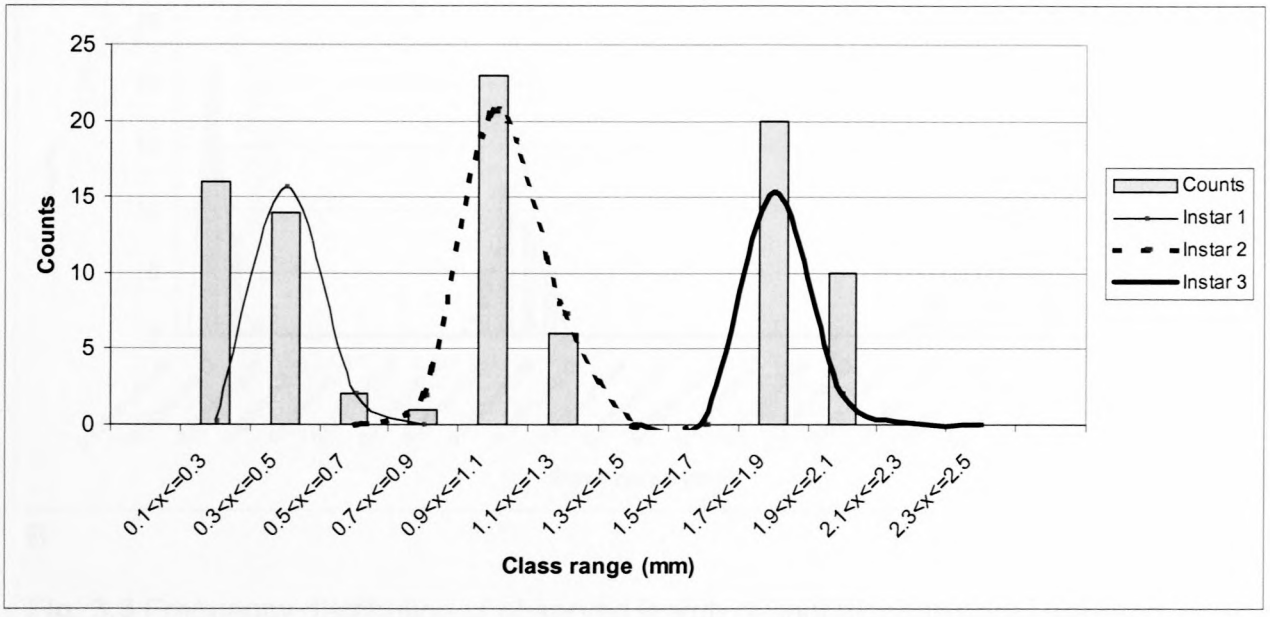


A



B

Fig. 3.2 Frequency distribution of observed body width (bars) and the estimated frequency of distribution for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* from a laboratory population.

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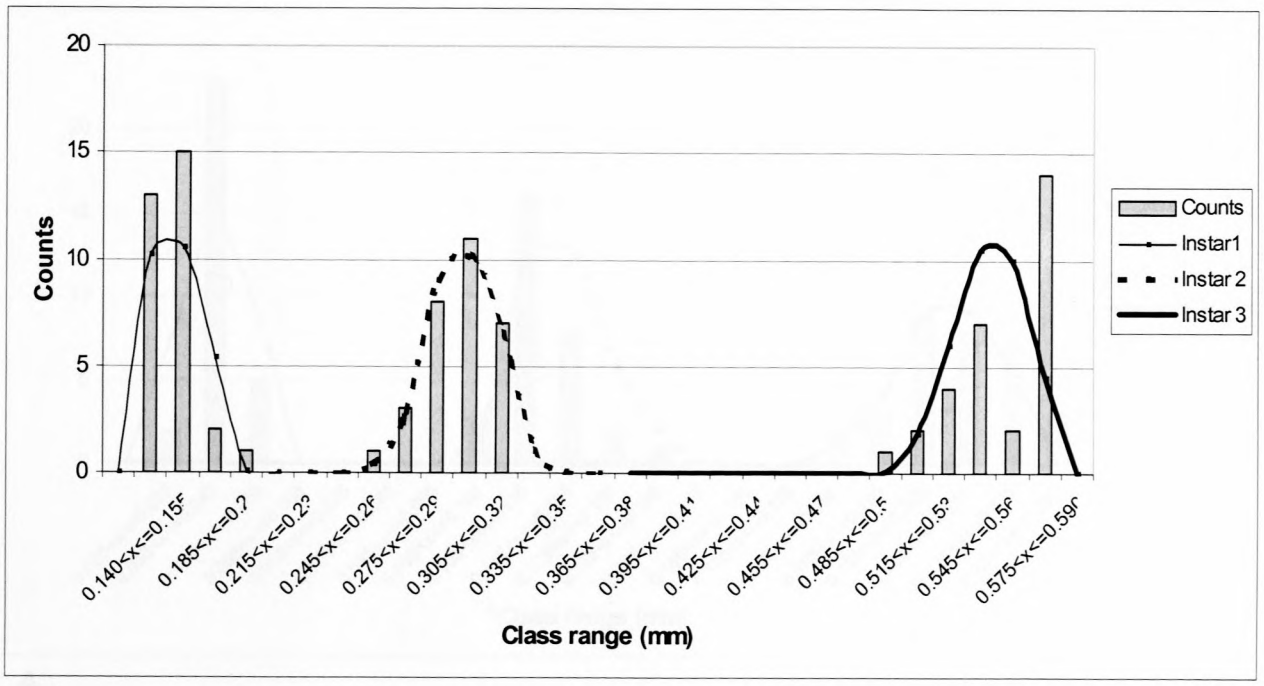

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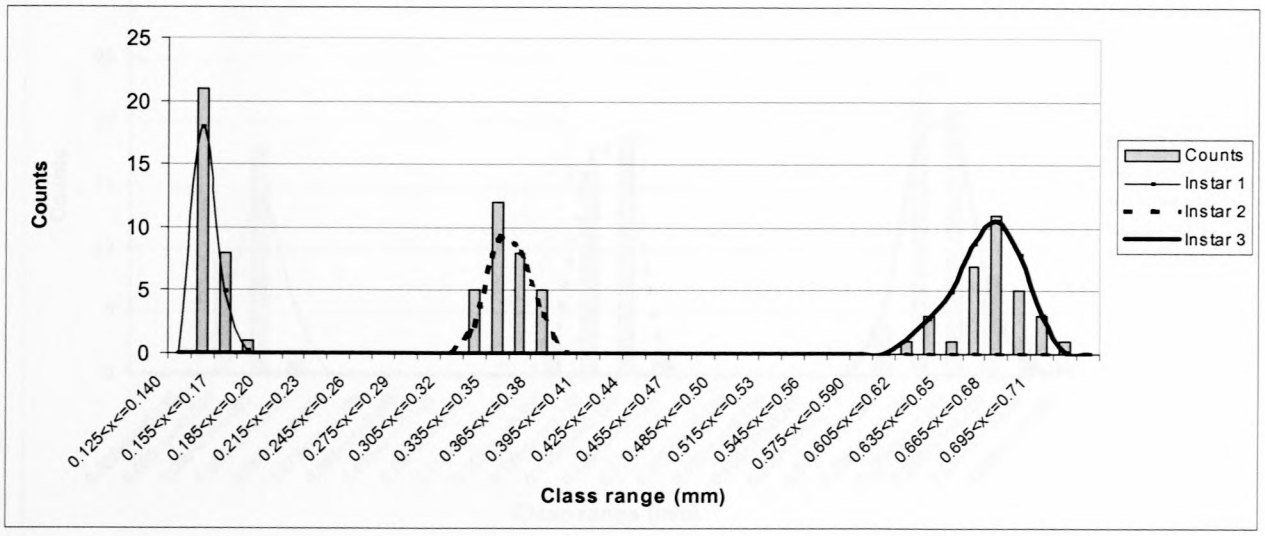

B

Fig. 3.3 Frequency distribution of observed length of cephalopharyngeal skeleton (tip to notch) (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* from a laboratory population.

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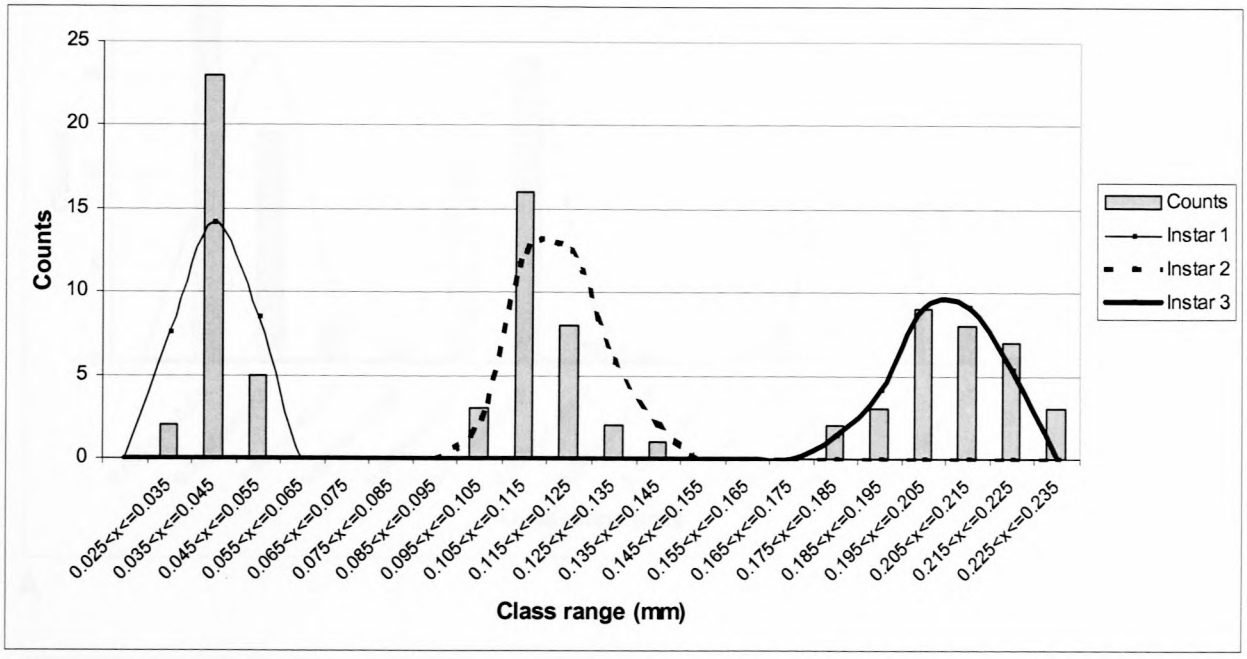

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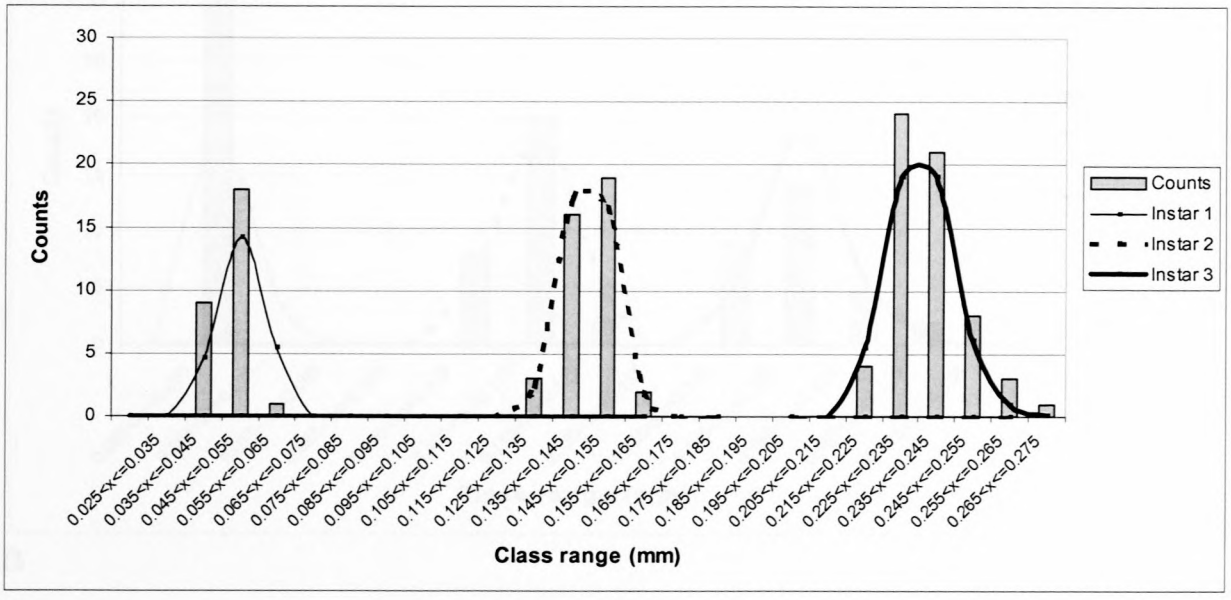

B

Fig. 3.4 Frequency distribution of observed mandible length (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* from a laboratory population.

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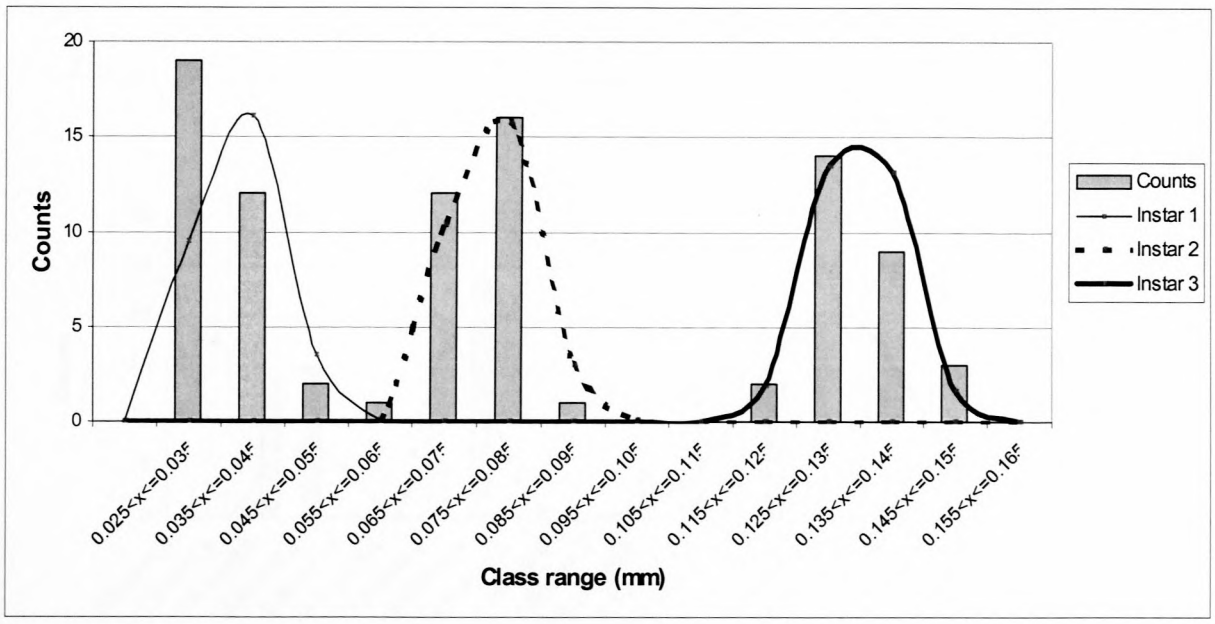

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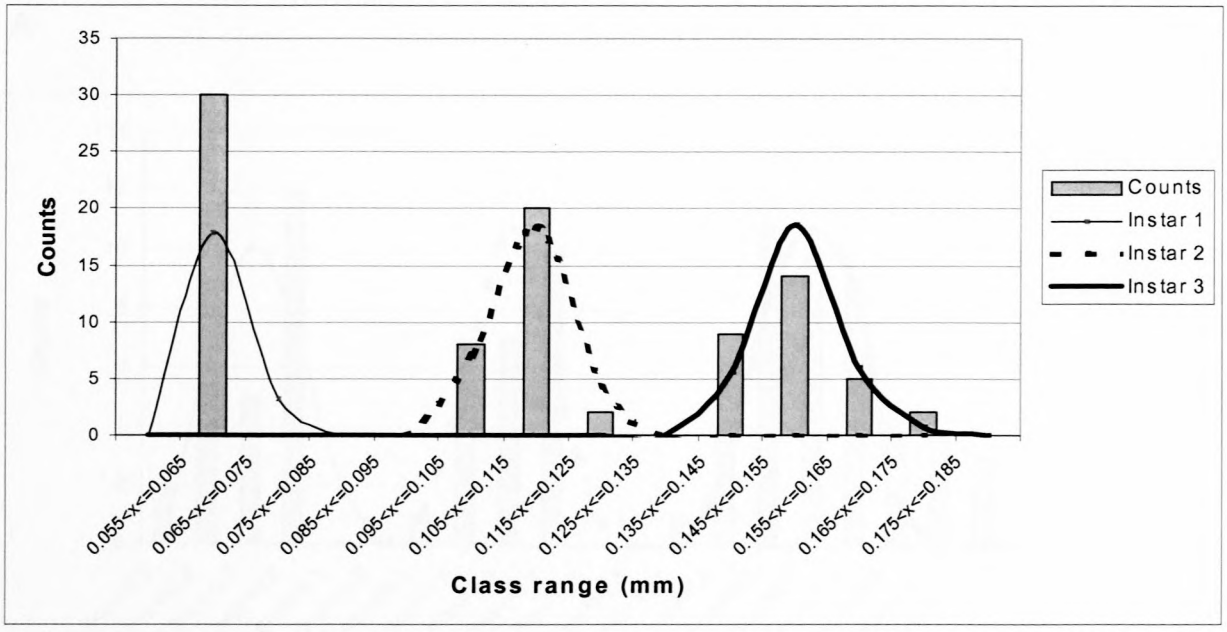

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Fig. 3.5 Frequency distribution of observed length of the mandible base (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* from a laboratory population.

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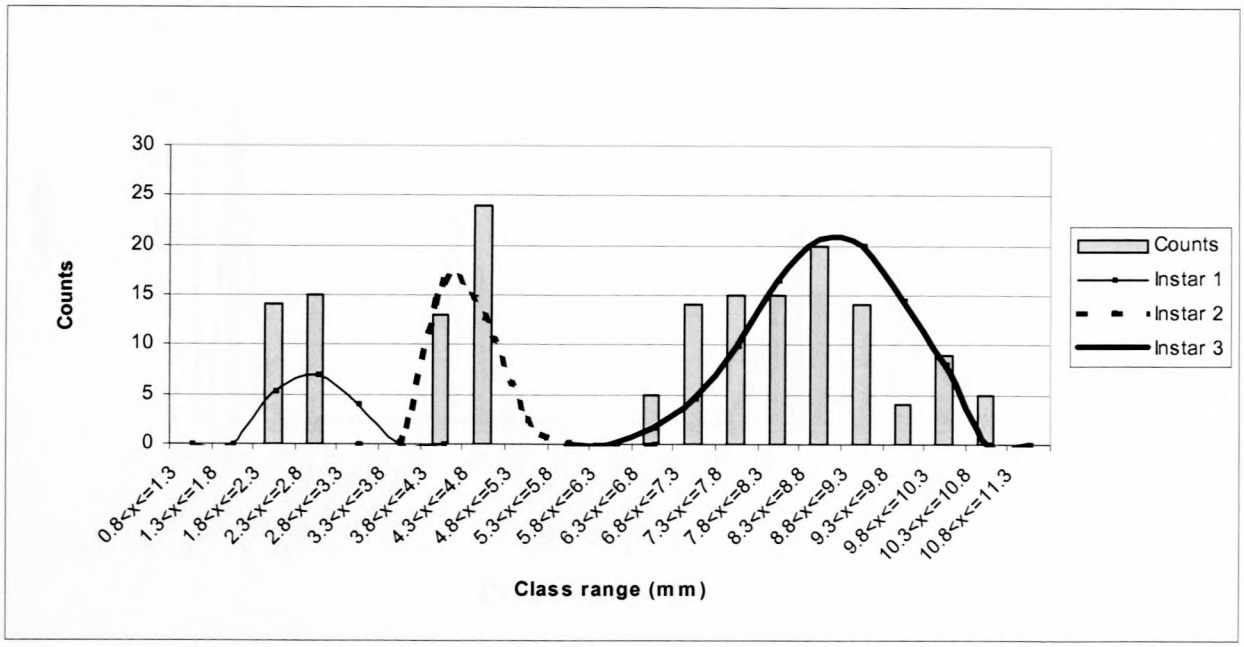

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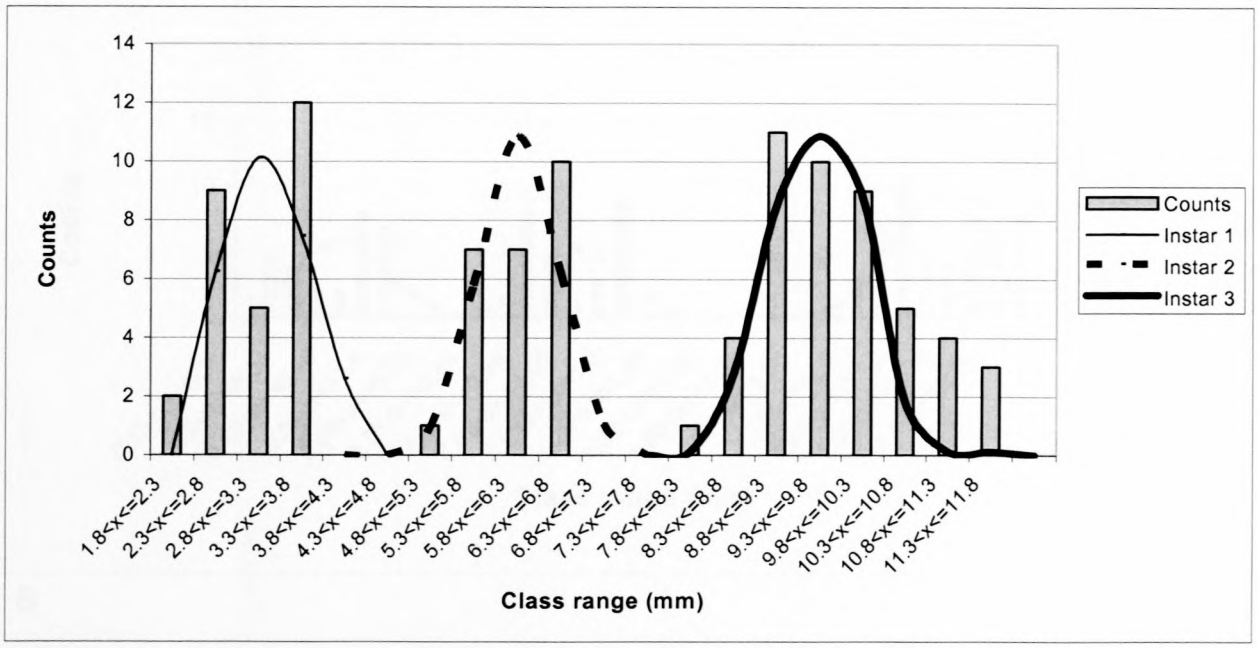

B

Fig. 3.6 Frequency distribution of observed body length (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* collected in the field.

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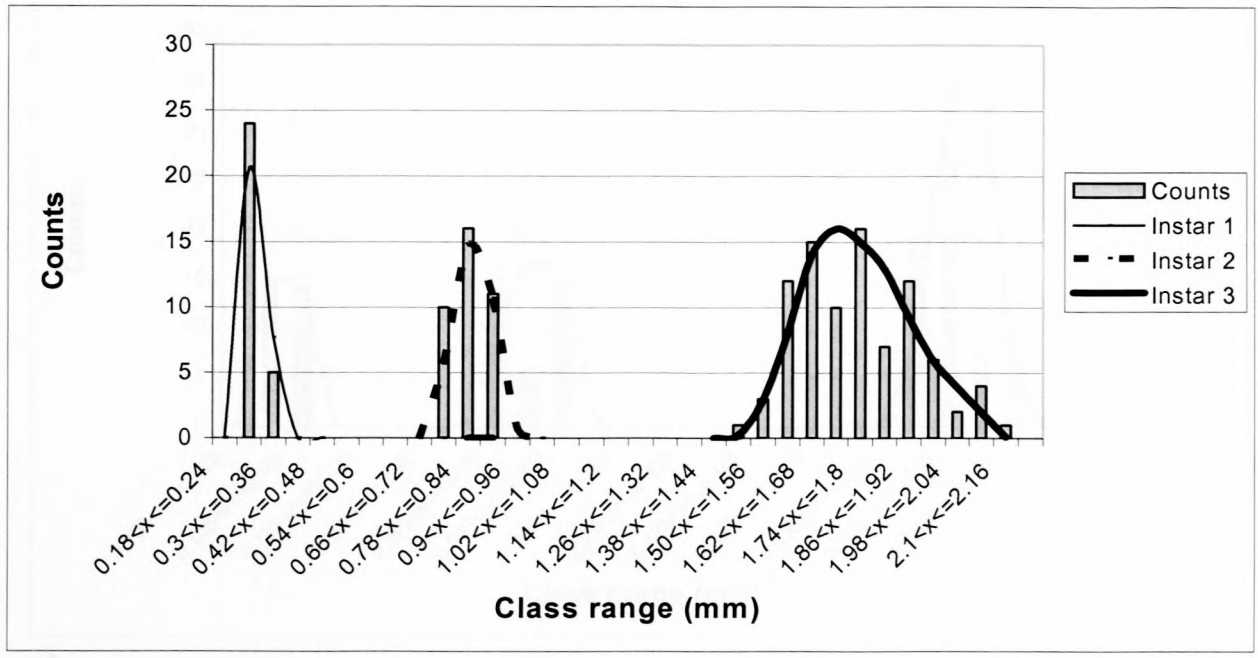

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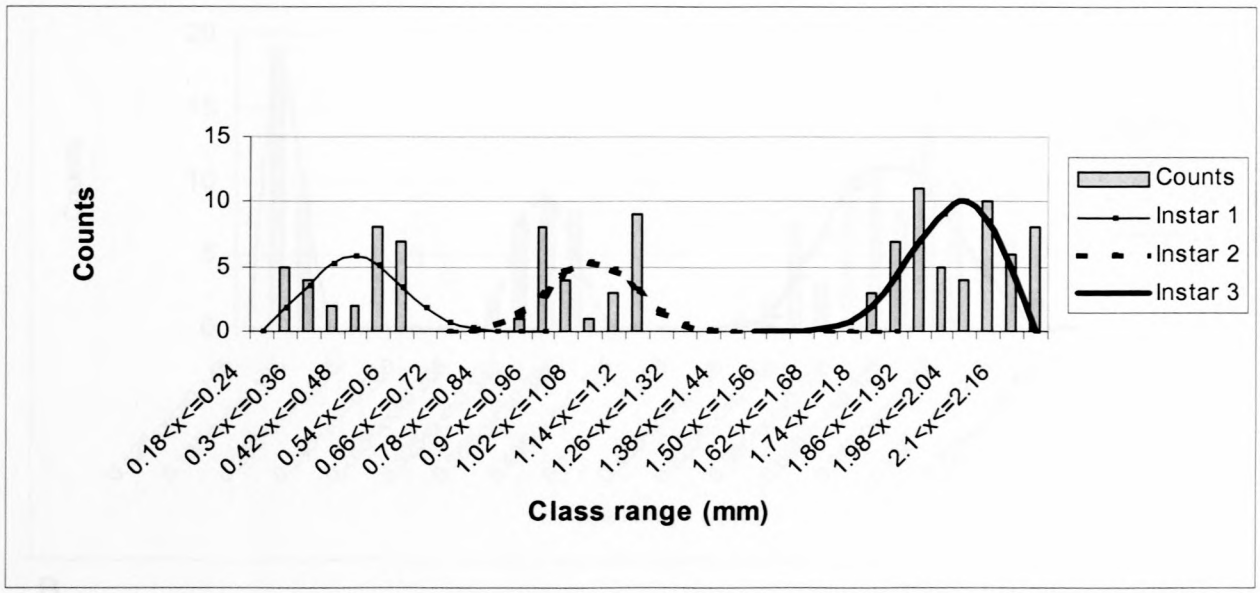

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Fig. 3.7 Frequency distribution of observed body width (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* collected in the field.

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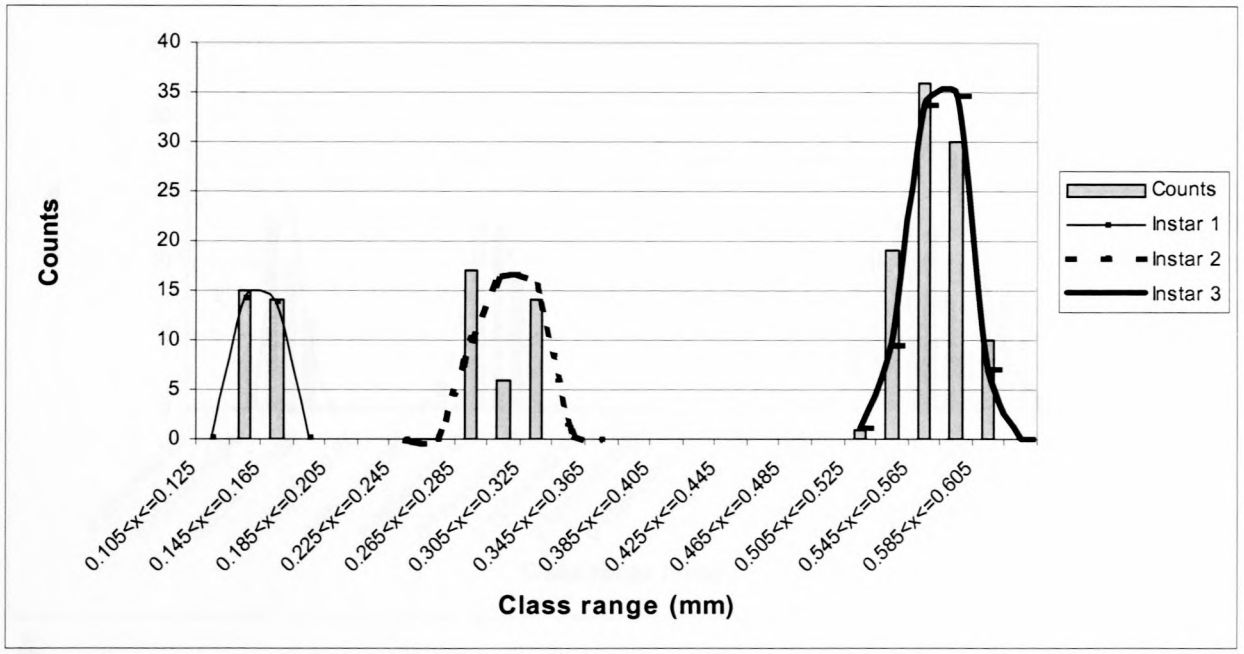

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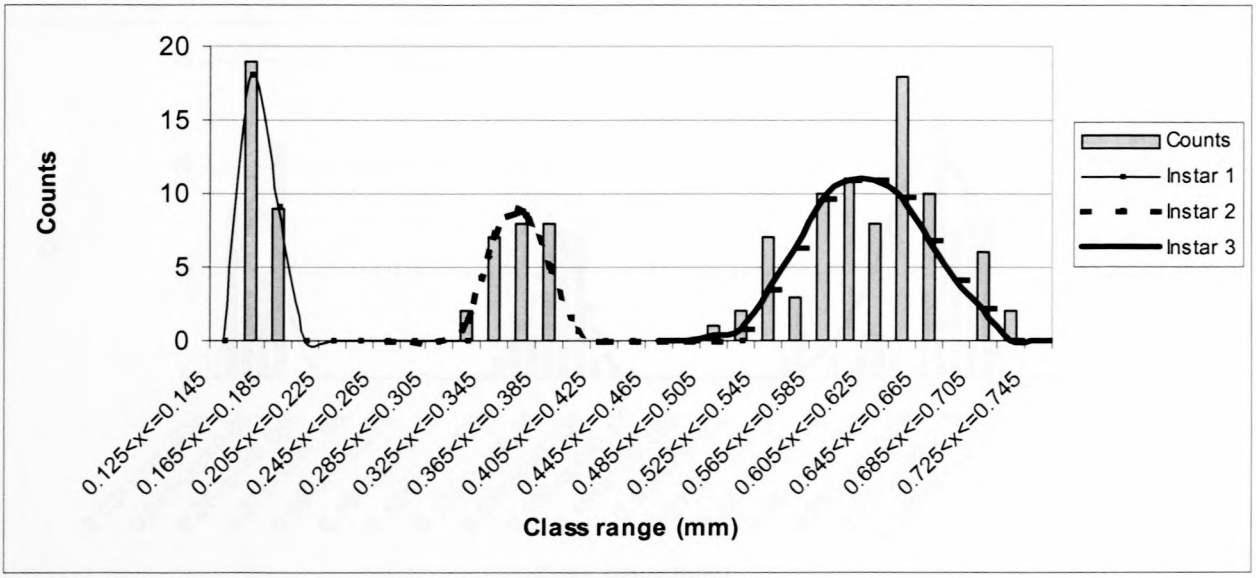

B

Fig. 3.8 Frequency distribution of observed length of the cephalopharyngeal skeleton (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* collected in the field.

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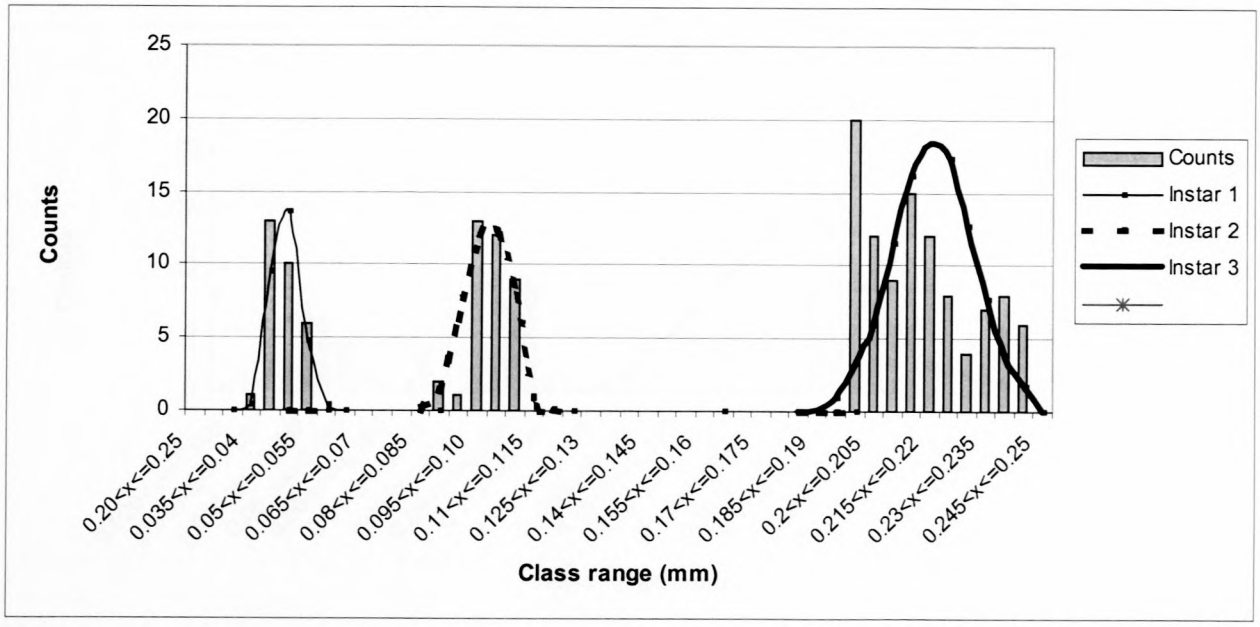

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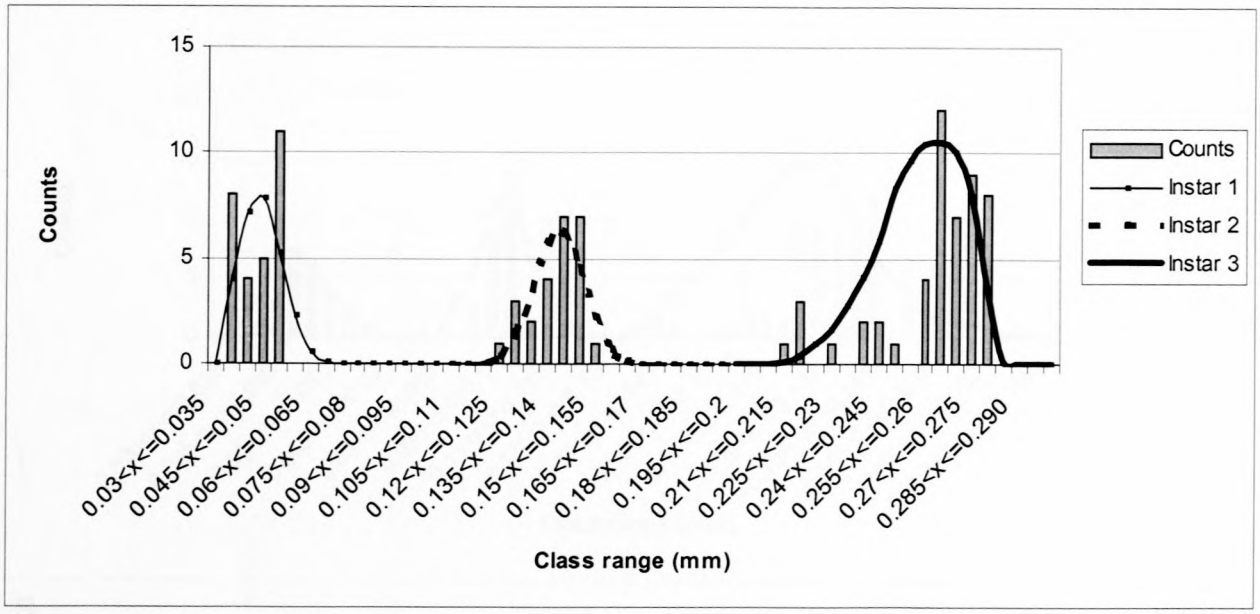

B

Fig. 3.9 Frequency distribution of observed mandible length (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* collected in the field.

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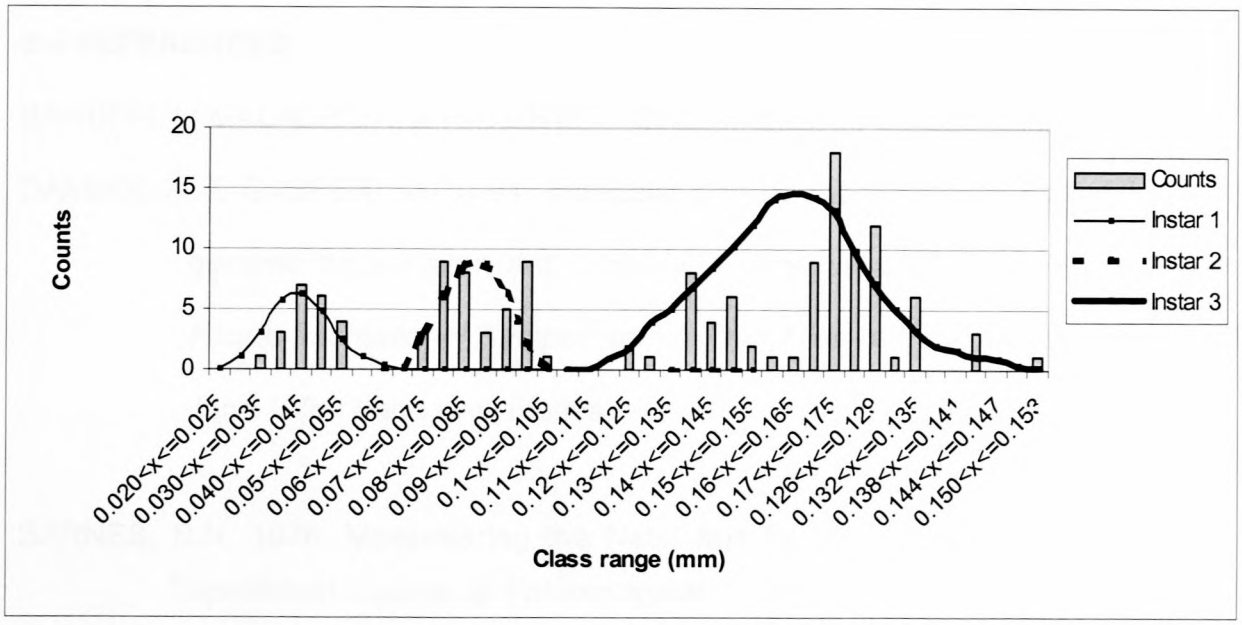

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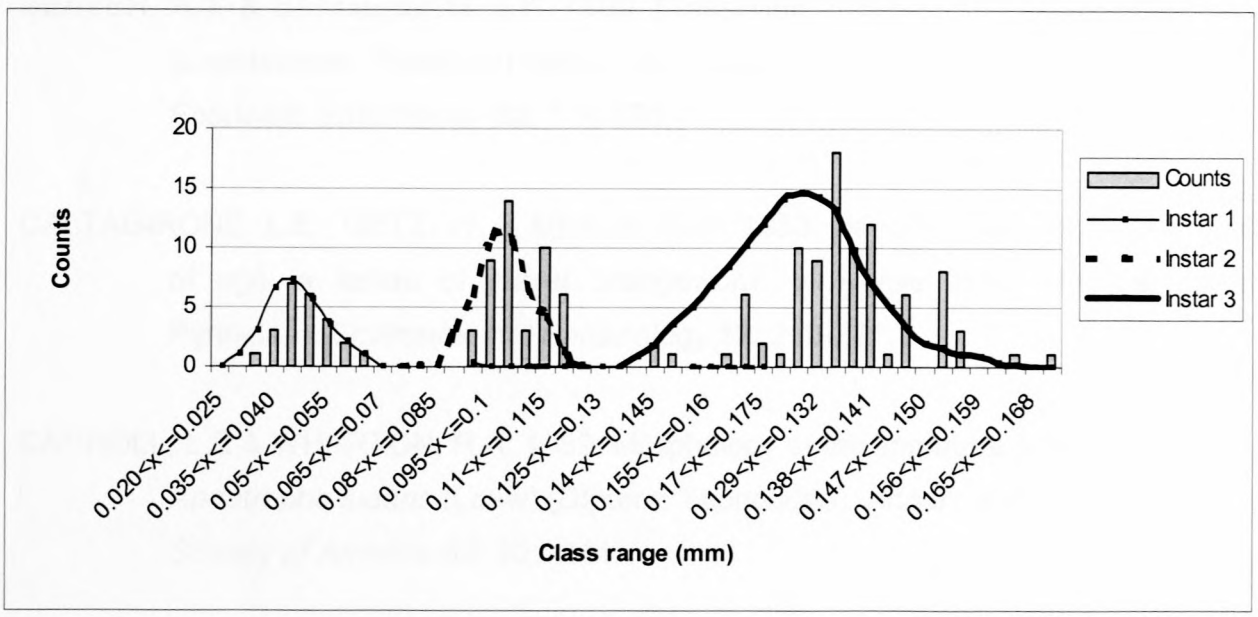

B

Fig. 3.10 Frequency distribution of observed length of the mandible base (bars) and the estimated frequency of distributions (lines) for instar 1, 2 and 3 obtained from the finite mixture analysis for A, *Ceratitis capitata* and B, *Ceratitis rosa* collected in the field.

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CHAPTER 4

SURVIVAL OF *CERATITIS CAPITATA* AND *C. ROSA* IN COMMERCIAL HOSTS IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA

4.1 INTRODUCTION

The Mediterranean fruit fly, *Ceratitis capitata* is one of the most polyphagous and important pests of edible fruits world wide (Weems 1981; Liquido *et al.* 1991). In Southern Africa, *C. capitata* has been found to attack citrus, stone fruits, deciduous fruits and a large number of other cultivated and wild fruit-bearing plants (Annecke & Moran 1982). The Natal fly, *C. rosa,* is an equally serious regional pest of many edible fruits, but is limited in distribution to Africa, Mauritius and Reunion (White & Elson-Harris 1992). As both *C. capitata* and *C. rosa* are native to sub-Saharan Africa, data on local factors that may limit population growth should be of some value to pest management programmes (Wharton *et al*. 2000).

During September (early spring) fruit flies are mostly found in lemon orchards in the Western Cape (Nel 1983). Nel (1983) also pointed out that this fruit plays an important part in the insect's seasonal cycle as it provides a place for survival during winter. During the summer months (December to February) there is an increase in the fruit fly populations in deciduous fruit orchards, associated with the ripening of the specific kinds of fruit or cultivars (Nel 1983). Table grapes are relatively free from fruit fly infestation during summer, although they can become heavily infested during some seasons if the vineyards are situated near permanent sources of infestation such as towns, with their home garden orchards containing a variety of fruit, including citrus, all year round.

The work described in Chapters 2 and 3 provided information on the identification of

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C. capitata and *C. rosa* larvae. Therefore, a study on survival of these species in different hosts in the Wetern Cape was feasible. If final instar larvae (developed from eggs deposited in fruit) are present in large numbers, the fruit would prove to be a suitable host. However, if only first instar larvae are present and no subsequent stages, then the fruit is probably unsuitable as a host. Therefore, the presence of different larval stages is not only a measure of susceptibility, but also of suitability as a host for a particular fruit fly.

The objectives of this study were firstly, to investigate the extent to which different (six) wine grape cultivars were infested by *C. capitata* under controlled laboratory conditions and secondly, to establish whether wild populations of *C. capitata* and *C. rosa* utilized wine grapes as alternative hosts in their seasonal cycle after adjacent stone fruits have been harvested.

4.2 MATERIAL AND METHODS

4.2.1 Field biology studies

Fruit fly infestation levels were monitored at five different experimental sites on commercial farms in the Western Cape Province, South Africa. This was achieved by placing fruit fly traps in orchards and in adjacent vineyards. On Morgenster, a plum orchard was situated adjacent to a Chardonnay vineyard. On Simonsig there were pear orchards next to Bukkettraube vineyard. On Klein Simonsvlei peaches were adjacent to a Pinotage vineyard and a plum orchard was located next to Colombard vines. At Verdun plums were adjacent to Merlot and Chardonnay vines and at Warwick plum orchards were adjacent to Cabernet Sauvignon vines. Sensus traps were used. Capilure baits (changed every eight weeks) were alternated with Ceratitis bait at Simonsig, Morgenster and

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Verdun. At Warwick and Klein Simonsvlei only Capilure baits were used. At all these sites Vapona was used in the Sensus traps to kill the fruit flies, preventing escape. Trap catches were collected, counted and the fruit flies were identified weekly. This study commenced in November 2000 and was terminated at the end of March 2001.

4.2.2 *In vitro* studies on the survival of *C. capitata* in different wine grape cultivars

Only *C. capitata* was used since *C. rosa* was not available from the Agricultural Research Council at the time this study was conducted. The *C. capitata* colony was reared at the Pest Management Division of the Agricultural Research Council (ARC), Infruitec-Nietvoorbij (Stellenbosch) at 25 ± 2°C, 65 ± 5% relative humidity with photophase between 07:00 and 17:00. Light was provided by overhead fluorescent tubes.

Four ml (approximately 200) of *C. capitata* pupae were placed in transparent Perspex cages. Each cage contained a Petri dish with water, and another one with food (a mixture of yeast hydrolysate and sugar in 3:1 ratio) which was changed weekly. Bunches of six wine grape cultivars, Pinotage, Colombard, Cabernet Sauvignon, Bukkettraube, Chardonnay and Merlot, were placed in the Perspex cages to act as hosts in the forced-oviposition and survival studies. After emergence from the pupae, females oviposited in the grapes by piercing the surface of the berries. The extent to which these eggs survived in each cultivar was determined. This was used as a measure of host suitability. The grape bunches in Perspex cages were replaced up to four times and the data were analysed using correspondence analysis. For this analysis the number of larvae in each instar were summed. The grape cultivars were entered as row variables and the dates (date on which the larvae were extracted) as column variables. Larval instars were entered as

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supplementary column variables.

4.3 RESULTS AND DISCUSSION

4.3.1 Field biology studies

The first principle axis of the correspondence analysis accounted for almost 88% of the variation, while the second accounted for about 8.5%. The three white wine cultivars (Colombard, Bukkettraube and Chardonnay) were the furthest to the left of the centroid (Fig. 4.1). Therefore, it appeared as if the first axis was determined by wine type. Colombard and Merlot were below the centroid and these two cultivars contained the highest number of early instar (first and second instar) larvae. Therefore, the instar present in the berries appeared to determine the second axis. The points for the first and second instar larvae, entered as supplementary column variables, were both well below the centroid, confirming the above conclusion.

The adult trap catches from the sites used in this study indicated that *C. capitata* was present in high numbers at a number of sites (Figs 4.2-4.6). High numbers of fruit flies caught in traps placed in fruit orchards were followed by high numbers caught in vineyards (Figs. 4.2-4.6). This was particularly evident at Klein Simonsvlei (Figs. 4.4a & b) and Warwick (Fig. 4.6a). Low numbers of *C. rosa* were trapped at all the sites. This suggested that this species (*C. rosa*) was not much of a threat at the sites used in this study. However, this does not necessarily contradict the opinion of other workers who recognised *C. rosa* as a major pest in the Western Cape Province (Nel, 1983) since this study was conducted over a limited area. In addition, if *C. capitata* is eradicated using SIT, *C. rosa* may fill the niche since both species are polyphagous.

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It was also possible that the trap catches obtained were not a true reflection of infestation levels by *C. capitata* and *C. rosa*. The attractants used in traps may have been more attractive to *C. capitata* than to *C. rosa*. Ware & Joubert (2001) recommended that Questlure should be routinely used for monitoring fruit fly populations and not Ceratitislure as used in this study. Ceratitislure should rather be used in surveys for *C. cosyra* in the Western Cape in order to determine whether this species is present (Ware & Joubert, 2001). Male attractants should not be used but if needed, Capilure would be suitable.

After the stone fruits were harvested in the studied orchards, it was highly likely that C. *capitata* and *C. rosa* utilised the neighbouring or adjacent vineyards as alternative hosts. The data obtained from the forced oviposition studies indicated that Colombard and Merlot were more susceptible to *C. capitata* than the other wine grape cultivars. This was implied by the ability of *C. capitata* eggs to hatch and survive to the third instar. These two cultivars (Colombard and Merlot) had the highest third instar larvae recovery, especially Colombard. Colombard is one of the cultivars grown at Klein Simonsvlei, the site which had the largest *C. capitata* catches in the vineyards. This verified the suitability of this cultivar as a host for *C. capitata*.

4.2.2 *In vitro* studies on the survival of *C. capitata* in different wine grape cultivars

During the oviposition period some grape bunches became contaminated with fungus, which could also have caused larval mortality, either directly or indirectly. Direct mortality from possible toxic by-products from fungal metabolism that affect larval development, or indirect mortality from toxic by-products affecting the symbiotic bacteria associated with *C. capitata* larvae are distinct possibilities (Hagen, 1966). However, the fungi could also have acted as source of protein.

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Jang (1986) found that certain metabolites are important for the development of *C. capitata* larvae from one instar to the next. It is suggested that different wine grape cultivars could be lacking in, or contain insufficient amounts of certain metabolites necessary for the development and survival of *C. capitata* larvae, thus further contributing to high larval mortality.

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Table 4.1 *In vitro* survival of *C. capitata* in different wine grape cultivars.

CULTIVAR	INSTAR	NUMBER OF LARVAE COLLECTED			
		28/01/01	9/2/01	22/02/01	10/3/01
Cabernet Sauvignon	1	0	0	0	0
	2	0	0	0	0
	3	9	16	12	6
Colombard	1	1	0	0	0
	2	4	3	0	0
	3	16	42	28	4
Pinotage	1	0	0	0	0
	2	0	0	0	0
	3	8	8	5	3
Bukkettraube	1	2	0	0	0
	2	0	0	0	0
	3	3	26	11	3
Chardonnay	1	1	0	0	0
	2	1	2	0	0
	3	3	11	4	2
Merlot	1	6	0	4	2
	2	14	9	14	0
	3	35	16	14	11

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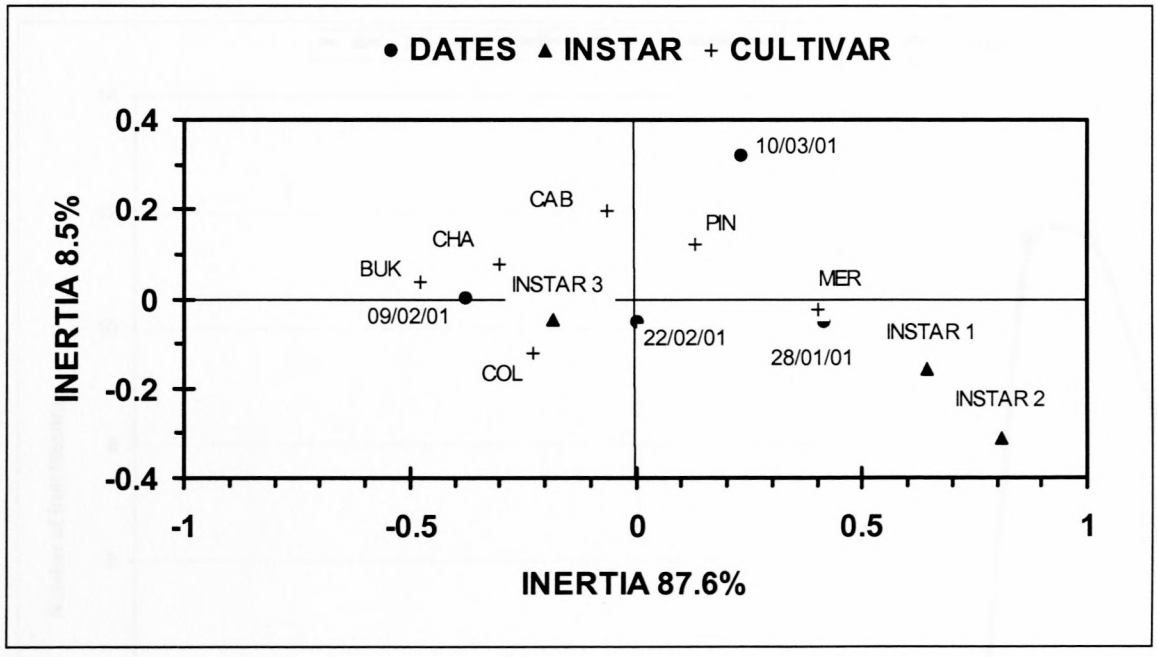

Fig. 4.1 Correspondence analysis on the survival *(in vitro)* of *C.capitata* larval instars in different wine grape cultivars.

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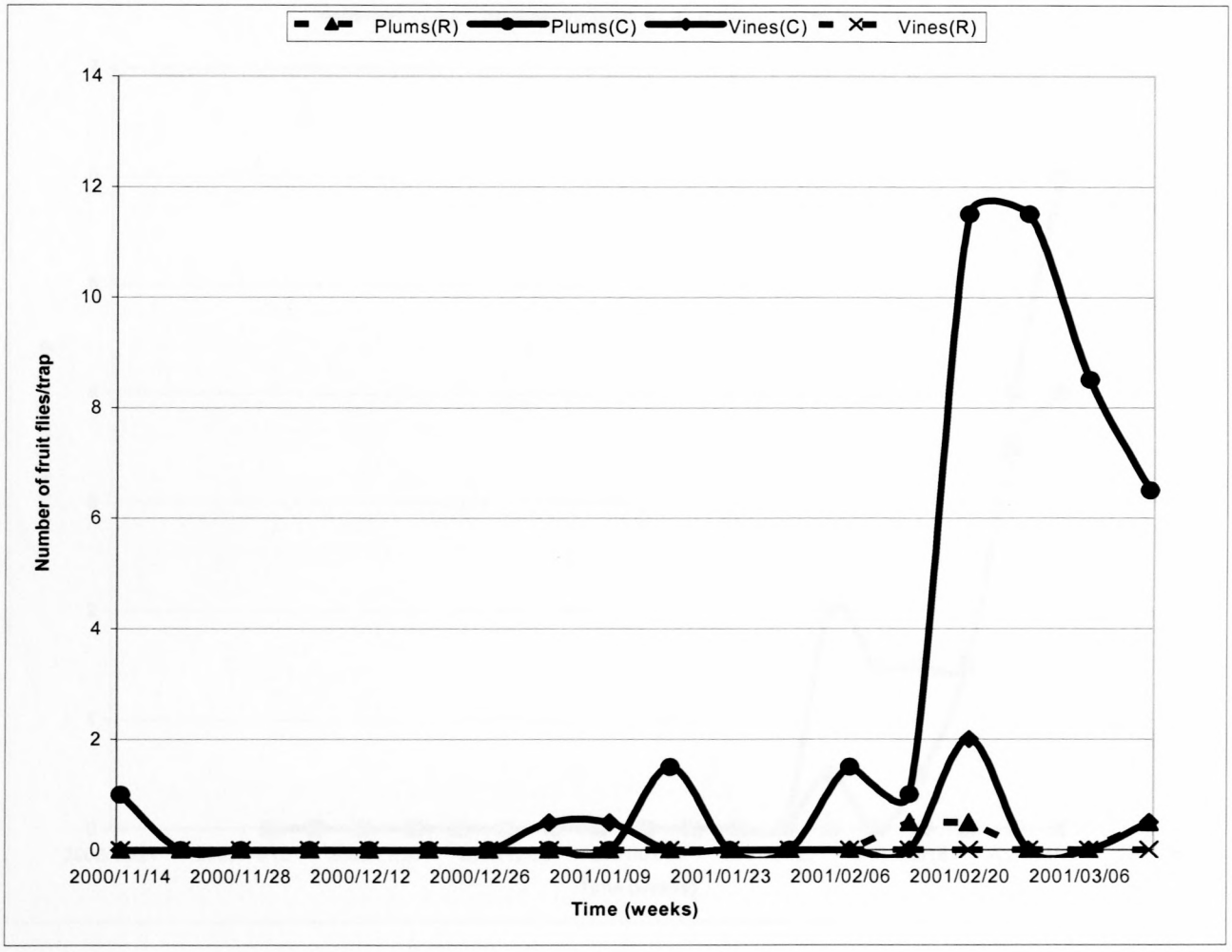

Fig. 4.2 Number of *Ceratitis capitata* (C) per trap in plums and vines, and *Ceratitis rosa* (R) in plums and vines at Morgenster

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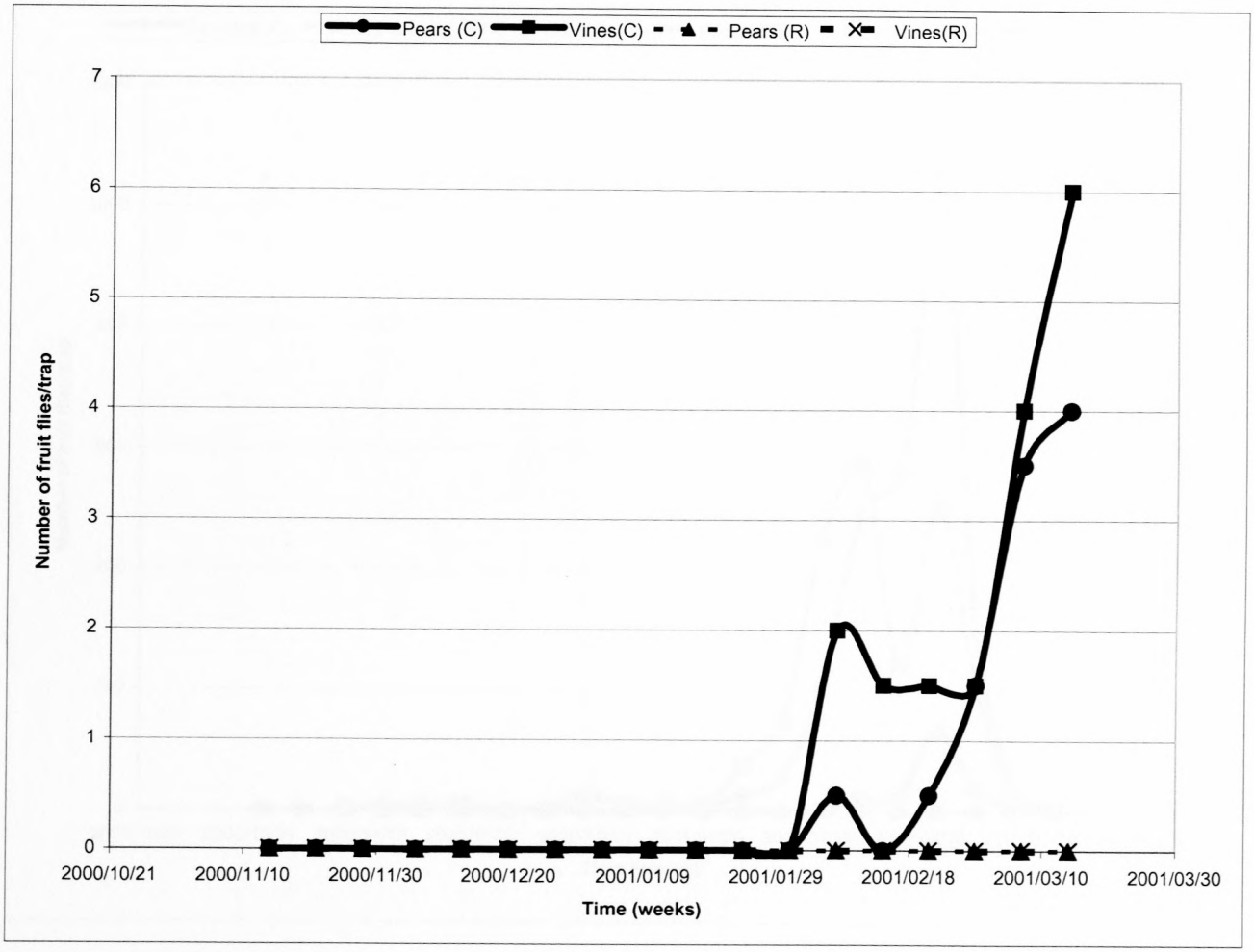

Fig 4.3 Number of *Ceratitis capitata* (C) per trap in pears and vines and *Ceratitis rosa* (R) in pears and vines at Simonsig.

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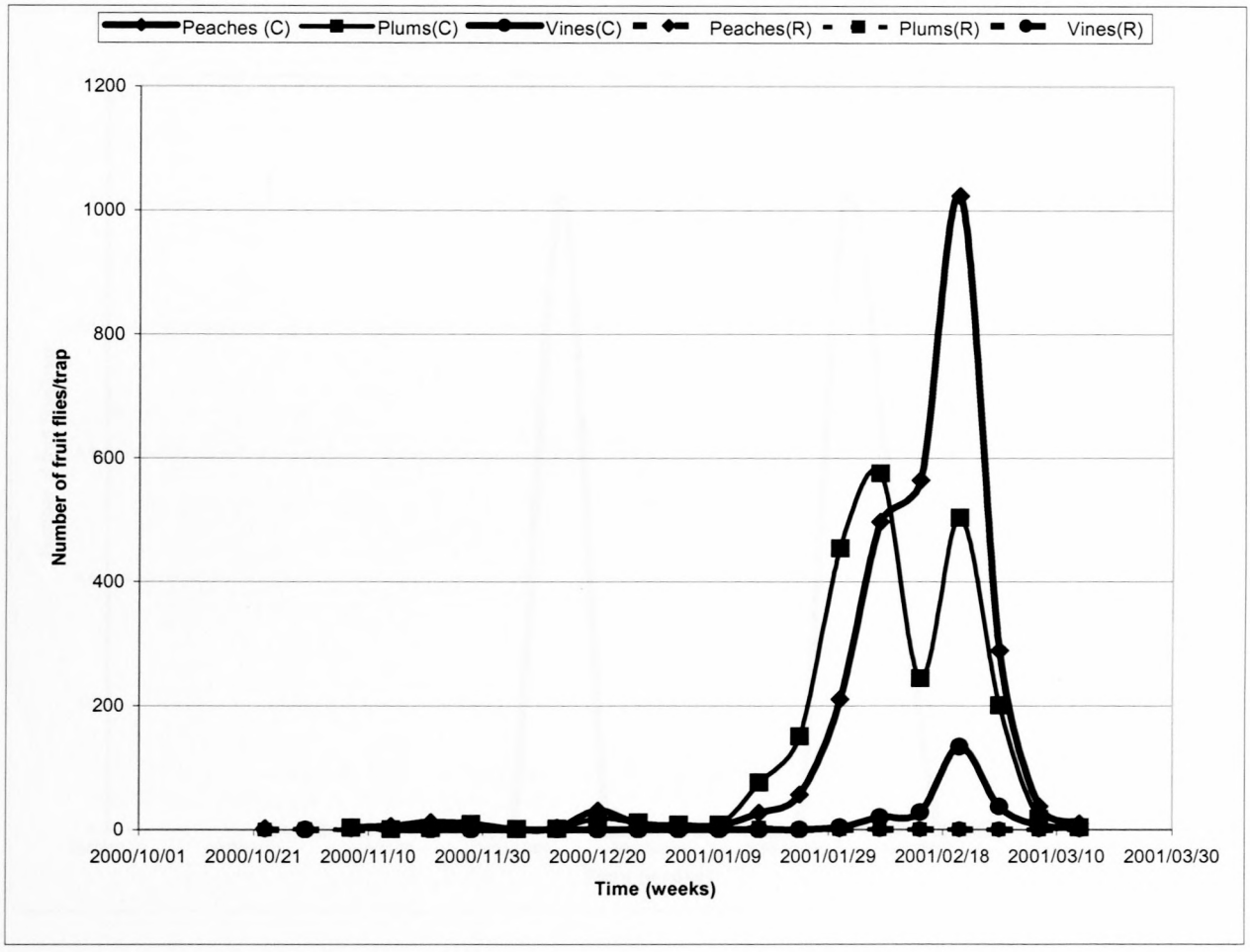

Fig.4.4 Number of *Ceratitis capitata* (C) per trap in peaches, plums and vines, and *Ceratitis rosa* (R) in peaches, plums and vines at Simonsvlei.

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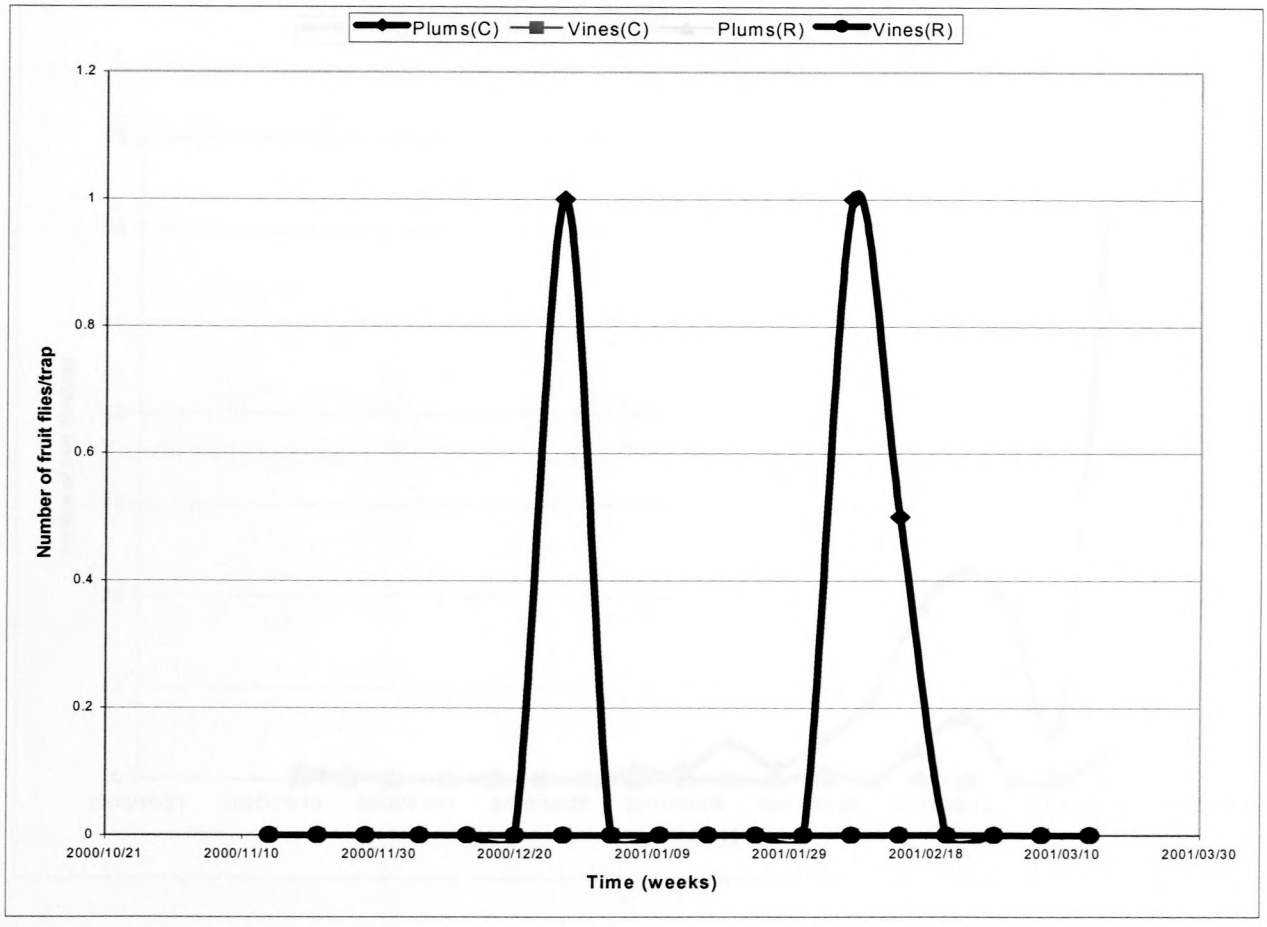

Fig.4.5 Number of *Ceratitis capitata* (C) per trap in plums and vines, and *Ceratitis rosa* (R) in plums and vines at Verdun.

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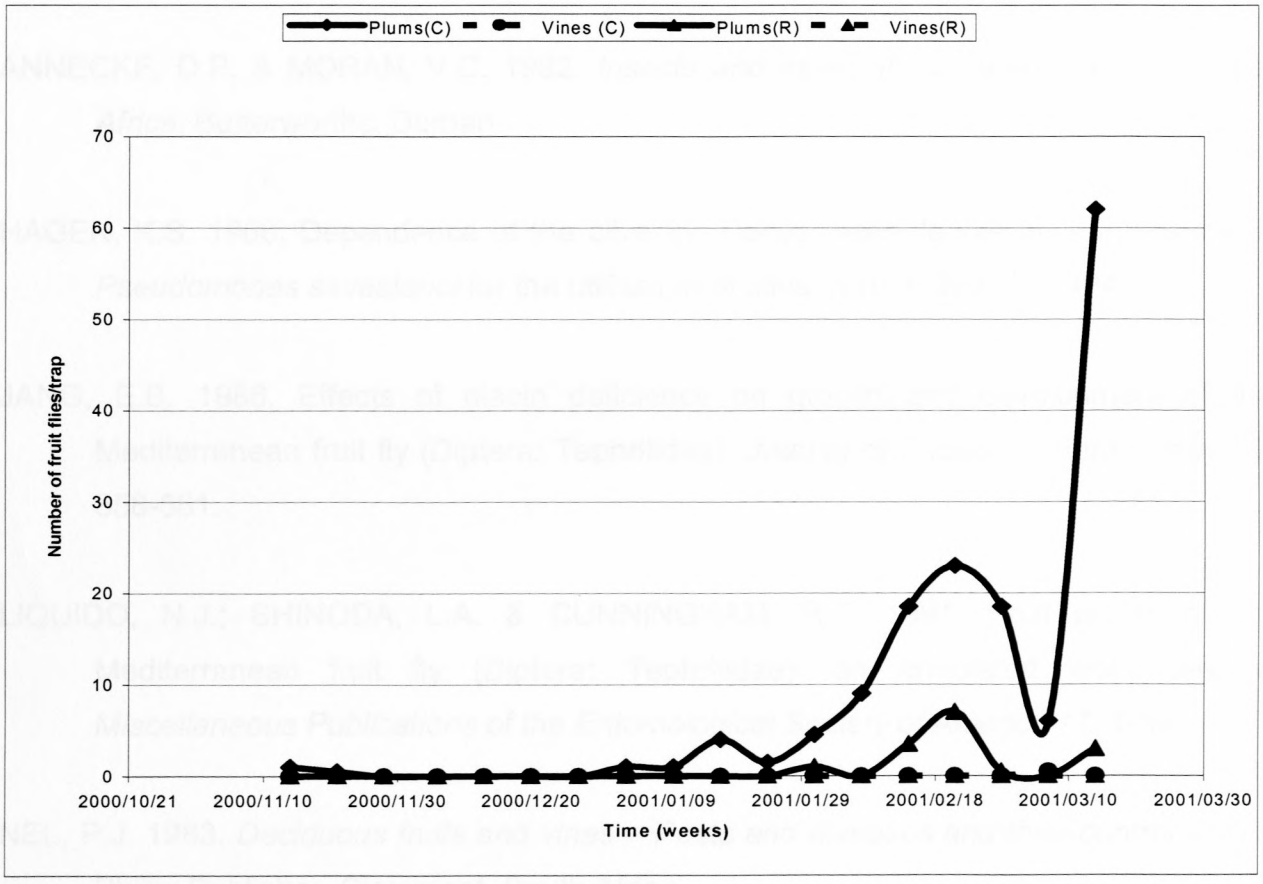

Fig. 4.6 Number of *Ceratitis capitata* (C) per trap in plums and vines, and *Ceratitis rosa* (R), in plums and vines at Warwick.

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CHAPTER 5

5.1 GENERAL DISCUSSION AND CONCLUSIONS

Modern fruit fly control programmes, like SIT, are species-specific (Knipling 1955; Klassen, 1989; Dent 1991; Gomes 1997) and since *C. capitata* and *C. rosa* have been identified as serious pests, it is imperative that intensive control programmes be put in place to prevent consequent economic losses. Of critical importance in any fruit fly control programme is the ability to identify the immature stages of the species concerned. Identification of the larval instars of *C. rosa*, which has been of long-standing interest, was accomplished in this study. Subsequently, its comparison with the local strain of *C. capitata* was also undertaken. The morphological features were more useful than size for discriminating between larval instars of *C. capitata* and *C. rosa*.

An identification key developed in this study can be used for differentiating between the larval stages of two fruit fly species. Characters such as anterior spiracles, mouthhooks, oral ridges and posterior spiracles clearly define the differences between larval instars of *C. capitata* and *C. rosa*. However, the absence of distinguishing features such as anterior spiracles and oral ridges in the first instar limit the ability to distinguish between the two species.

Alternatively, other features which are well-developed and clearly defined at first instar level be investigated, examined and used as characters of taxonomic importance. However, this will inevitably require the use of SEM, as opposed to light microscopy, a cheaper and more convenient method.

The effect posed of nutritional quality and environmental factors (temperature,

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relative humidity and photoperiod) on the size of larval instars (groups) can result in misleading conclusions in a morphometric study (Schmidt & Lauer, 1977).

The relative abundance of *C. capitata* and *C. rosa* in fruit orchards and adjacent vineyards showed that vineyards were potential alternative hosts that played a role in the fruit fly's seasonal cycle. The high numbers of adult *C. capitata* caught in traps indicated that this species was a serious pest at the study sites. However, the extremely low numbers of *C. rosa* caught suggested that this fruit fly was not a threat at these sites. It is possible that the trap catches were not a true reflection of the infestation levels at the sites as the lure used may have been more attractive to *C. capitata* than to *C. rosa*.

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