BIOLOGY AND BIOMETRY OF *Neochetina eichhorniae* Warner (CURCULIONIDAE: COLEOPTERA) AND THE NATURE OF DAMAGE CAUSED BY IT ON *Eichhornia crassipes* (Mart)

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Biology and Biometry of Neochetina eichhorniae Warner (Coleoptera: Curculionidae) and the Nature of damage caused by it on Eichhornia crassipes (Mart.)" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship or other similar title, of any other University or Society.

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We, the undersigned members of Advisory Committee of **Sri. Sreekumar, K.M.**, a candidate for the degree of Master of Science in Agriculture with major in Agricultural Entomology, agree that the thesis entitled "Biology and Biometry of Neochetina eichhorniae Warner (Coleoptera: Curculionidae) and the Nature of damage caused by it on Eichhornia crassipes (Mart)" may be submitted by Sri. Sreekumar, K.M. in partial fulfilment of the requirements of the degree.

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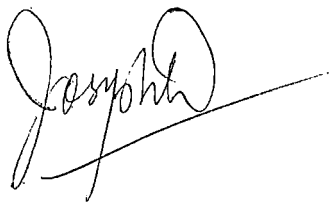

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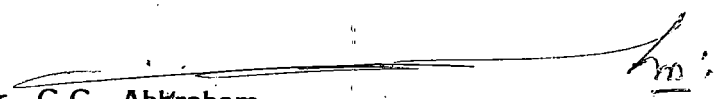

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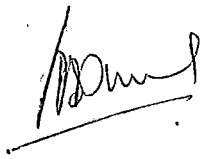

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Introduction

INTRODUCTION

Water hyacinth (Eichhornia crassipes (Mart) Solms.) is a free-floating fresh water plant which is an inadvertent introduction from its native home, the Neotropics. The plant, thus escaped from the regulatory mechanisms of nature, multiplied at an alarming proportion and became one of the dreaded weeds of the water bodies of the world. It is distributed throughout the tropics and subtropics covering extensive areas of several water bodies. This plant made its entry into India before 1900 (Gopal and Sharma, 1981) and infests more than 0.2 million ha of water surface at present (Govt. of India, 1979).

The damage caused by this plant to the environment is beyond estimation. Profuse growth of the plant chokes the water body completely, resulting in depletion of oxygen which in turn leads to reduction in the population of phytoplanktons.

In Kerala the rapid proliferation and spread of this weed in paddy fields, canals, and navigation systems of Ernakulam, Kottayam, Alleppey, Quilon and Trivandrum districts has been causing serious problems to agriculture, aquaculture navigation and public health. Weed choked water body is an ideal habitat for mosquito breeding.

Several methods including manual weeding were tried for controlling this weed. All these methods have been found to be expensive and unsatisfactory for large scale adoption.

Several herbicides were used against this weed, of which 2,4-D, diquat and paraquat were found to be relatively more effective. But the use of these herbicides cannot be recommended in water bodies due to severe pollution problems. Sankaran (1982) reported that manual, mechanical and chemical methods have so far failed to bring the weed under control.

Ineffectiveness of the conventional control measures has brought out the need for alternative approaches including biological control. As a result of extensive surveys, many natural enemies were identified, and evaluated. These included fishes, phytopathogens, mites and insects.

The mite Orthogalumna terebrantis Wallwork and the fungus Conospora rodmanii Conway were found to be promising agents, but failed to inflict lethal injury to the weed when used independently.

Among the insects, the weevils Neochetina eichhorniae Warner and N. bruchi Hustache have been suggested as potentially successful agents. The species N. bruchi successfully controlled the weed in Argentina (Deloach and Cordo, 1983).

After extensive host specificity tests, the weevils were introduced into India in 1982 under the All India Co-ordinated Research Project on Biological control of Crop Pests and Weeds, and field releases

were initiated in 1983. Jayanth (1988) reported that more than 95 per cent infestation by the weed in a 20 ha tank at Bangalore was cleared within 32 months after the release of the weevil N. eichhorniae.

Eventhough the insect was released in Kerala in 1983, no significant control was achieved even after six years. In the use of this insect in the integrated management of the weed, certain lacunae in the existing knowledge about the bioagent has been felt. The present studies have been taken up to generate information on the following aspects:

1. Biology of N. eichhorniae under Kerala conditions,

2. To study the morphology and biometrics of the insect with a limited objective of identifying the larval instars among the field population and differentiating the sexes,

3. Nature of damage caused by the insect to the plant,

4. Destructive potential of the insect under free-floating and rooting type of growth of the plant and to determine the optimum release load of the insect required per unit area for effective control of the weed, and

5. Estimation of field population of adult weevils harboured by the plants on the basis of number of feeding scars on the leaves.

Review of Literature

REVIEW OF LITERATURE

Water hyacinth is considered to be one of the most troublesome weeds of the world. Today the weed is distributed in the waterbodies throughout the tropics and subtropics. Man had tried several methods to control this weed. These consisted of mechanical, chemical and biological methods. Among the bio-control agents, the weevil Neochetina eichhorniae Warner attained special importance. In this chapter, the available literature on the origin, distribution and methods of control of water hyacinth is reviewed, with special reference to the use of N. eichhorniae as a bio-agent.

2.1 Origin and distribution of water hyacinth (Eichhornia crassipes (Mart.) Solms).

Water hyacinth was first described by Von Maritus in 1824 under the name Pontederia crassipes. The nomenclature was later corrected by Solms Laubach as Eichhornia crasspies in 1883. The Neotropics is considered to be the native place of water hyacinth without referring to a specific region (Smith and Merchant, 1961).

At present, the weed is distributed throughout the world in the tropics and subtropics and its area extend from 40°N to 45°S latitude (Holm et al., 1977). The spread of this weed to North, South and Central America,Asia, Australia and Oceania, Africa and Europe is

supported by various reports. (Gay and Berry, 1960; Little, 1967; Frye, 1972; and Gupta, 1973) Biswas and Calder (1954) stated that the weed got established in Bengal near about 1896. This view was later supported by Gopal and Sharma (1981) who opined that though definite reports of the time of entry of this weed into India was lacking, its arrival into Bengal took place well before 1900. In India, water hyacinth covers more than 0.2 million ha of water surface (Govt. of India, 1979).

2.2 Effect of water hyacinth on environment

Kar (1939) reported that water hyacinth interfered with seed germination, and seedling establishment in rice. The detrimental effect of water hyacinth to fish and other aquatic forms of life was reported by Rao (1969). Mc Vea and Boyd (1975) reported that water hyacinth suppressed the growth of phytoplanktons and submerged plants. The plant provided both the habitat and food for several harmful animals and vectors of diseases like malaria, encephalitis and schistosomiasis (Dassanayke, 1976). Water hyacinth in dense growth could obstruct water flow in irrigation channels, interfere with navigation and hydro-electric power generation (Krishnamoorthi, 1976).

2.3 Different methods of control

The methods by which the weed was attempted to be controlled included manual, mechanical, chemical and biological.

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2.3.1 Manual and mechanical control

In confined water bodies, manual clearing of water hyacinth was commonly adopted. Pre-rainy period (April-May) was found to be more suitable for manual removal, as the weed was then confined to a relatively smaller area (Ambasht and Ram, 1976). Phillippose (1963) reported that depending on the density of the weed mat, 100 to 300 man-days per hectare were required to remove the weed.

In another method, the inability of water hyacinth to tolerate salt had been made use of. In coastal areas in India, tidal sea water was used successfully to control the weed (Gupta, 1976). Hamdoun and Tighani (1977) pointed out that manual control was very expensive, time consuming and unsatisfactory.

Several mechanical devices were developed by many workers to collect the weed mass for destruction. The Army Corps of Engineers in USA developed several equipment from time to time (Tabita and Woods, 1962). In India such machines were developed at the Central Institute of Fisheries Technology, Cochin (Velu, 1976). However, none of the mechanical control devices was found to be promising. According to Soerjani (1977), different kinds of machines were required to operate in shallow and deep water bodies. Apart from high cost, cent per cent removal of the weed was not possible and the few plants left out in the waterbody multiplied quickly to cover water surface again.

2.3.2 Chemical control

Considering the limitations of mechanical control, various chemicals have been tried against the weed. The earlier chemicals included, among others a number of inorganic compounds like formalin, barium chloride, sodium chloride and sulphuric acid (Bose, 1945). Later, 2,4-D replaced all other previously used chemicals and several formulations of the compound were tried in almost all countries where the weed was observed. Hitchcock et al. (1959) found that 2,4-D at the rate of 15-30 mg per kg of water hyacinth was effective for sinking the mat. The weedicide was applied @ 2 to 11.2 kg/ha and the weed mat sank within 2-3 months after spraying. Studies at Hissar (HAU, 1972) revealed that 2,4-D ester @ 3 l/ha gave cent per cent control within thirty days after application.

Two sprays of diquat or paraquat at 0.4 to 1.6 ppm were effective in 3 to 4 months (Ball, 1959), Cohee (1967) reported that Amitrol-T was more mobile and its better translocation resulted in eventual death of even attached untreated plants.

Chemical control, though quick and effective posed several problems. The rapid kill of a large thick mat of the weed added a huge quantity of organic matter to the water body which sank to the bottom and released a large amount of nutrients. This resulted in development of algal blooms and general eutrophication (Naidu and Singh 1958). Further, chemicals used in the water bodies often moved out of the

system in many ways and affected organisms far away from the site of treatment. Many chemicals persisted and adversely affected the water quality (Faust and Aly, 1962). Besides, the removal of plant cover provided suitable conditions as increased sunlight penetration and availability of nutrients for the germination of seeds of water hyacinth itself and reinfestation (Pettet, 1964).

2.3.3 Biological control

Sankaran (1982) reported that water hyacinth multiplied at such an alarming proportion that manual, mechanical and chemical methods failed to keep it under control. Since water hyacinth is a pest, mainly because of its very high rate of vegetative reproduction, a biological agent that suppresses its prolificity would be potentially effective. The bio-agent shall be host specific and be able to grow and reproduce in the environment. If these conditions are fulfilled, biological control offers the cheapest and most effective longterm measure with minimum detrimental impacts on the environment. Biological control agents of water hyacinth reported so far include phytopathogens, insects, mites, snails, fish and manatee.

2.3.3.1 Snails and Manatee

Among the snails, Marisa cornuarietes was found to feed on the roots and parts of leaves of water hyacinth in Puerto Rico (Bennet, 1968). It pruned and inhibited flowering, but did not help in control

of the weed. It preferred submerged plants and hence in mixed stands, water hyacinth increased (Rushing, 1974).

Manatee (Trichechus manatus.) had also been suggested for controlling hyacinth, but it was not effective because it preferred other weeds to water hyacinth for feeding (Allsopp, 1969).

2.3.3.2 Fish

The chinese grass carp (Ctenopharyngodon idella Valencieunes) as a promising agent was reported by Andres and Davis (1971). However, Mehta and Sharma (1972) tried it without success in India.

2.3.3.3 Phytopathogens

Nagraj and Ponnappa (1970) reported Myrothecium roridum var eichhorniae, Corticium sasaki, Marasmiellus inorderma and a new species which was later named as Alternaria eichhorniae from water hyacinth. Acremonium zonatum from Louisiana was reported by Rintz (1973). On the basis of extensive studies he concluded that the pathogen was not capable of inflicting significant damage to the plant and did not hinder its prolific growth and hence not to be suitable for biological control. Charudattan et al. (1976) reported Bipolaris stenospila as a pathogen of water hyacinth from the Dominican Republic.

However Freeman et al. (1976) pointed out that the fungus attacked bermuda grass and sugarcane. Conway (1976) observed that the fungus Cercospora rodmanii caused severe damage to water hyacinth in Rodman reservoir. He demonstrated that the fungus could be cultured and sprayed on the plants resulting in high degree of infection and subsequent damage. The use of C. rodmanii as a biocontrol agent for water hyacinth had been patented by the University of Florida and a commercial product of the fungus was developed in co-operation with Abbot Laboratories, Chicago (Conway and Freeman, 1978).

Templeton et al. (1979) pointed out some of the constraints in the use of mycoherbicide, as host resistance, environmental and spatial isolation of the host, as well as narrow environmental requirements for infection, spore dormancy and long incubation period of fungi. In addition, fungi are subjected to competition, predation and parasitism.

2.3.3.4 Mites

The mite Orthogalumna terebrantis Wallwork (Acarina: Galumnidae) was studied in detail (Perkins, 1973, Cordo and Deloach 1975). This was considered to be one of the most promising biological control agents on water hyacinth (Perkins, 1973). Fosse (1978a) showed that O. terebrantis in conjunction with the weevil N. eichhorniae produced increased damage on water hyacinth. Fosse (1977) studied the temperature optima for the development of O. terebrantis and found that

10-30°C temperature range was the best for overall development. Many phytopathogens are incapable of imparting lethal damage to the weed. Inspite of the limitations to the use of mycoherbicides, the fungus, C. rodmanii appears to be a promising one. The mite O. terebrantis also appears to be promising. However the fungus and the mite failed to inflict lethal injury to the weed when used independently.

2.3.3.5 Insects

Ever since the concept of biological control as a means of controlling the weeds was considered, insects received particular attention as biological control agents (Huffaker, 1964).

Bennet and Zwolfer (1968) explored for natural enemies in Northern regions of South America and Trinidad. They considered the weevil Neochetina bruchi Hustache (Curculionidae: Coleoptera), the lepidopteran stem borers Acigona ignitalis Hmps., and Epipagis albiguttalis Hmps (Pyralidae) and the aquatic grass hopper Cornops longicorne (Brunner) (Acrididae) to be promising. Later it was found that two species of weevils, N. bruchi Hustache and N. eichhorniae Warner were involved. Sankaran and Rao (1972) studied the natural enemies of water hyacinth and reported that 13 insects were found feeding on the weed. Perkins (1974) listed about 70 species of arthropods which had been reported to occur on water hyacinth. Of these, 26 species occurred in USA, 30 in Uruguay and 13 in India.

2.3.3.5.1 Insects other than N. eichhorniae

Deloach (1976) reported that N. bruchi strongly preferred E. crassipes in a variety of laboratory tests. Host specificity mainly manifested in larval feeding and pupation but was slightly less in ovipositional preference and survival. He suggested that N. bruchi was sufficiently host specific for introduction into United States. The first case of biological control of water hyacinth by the weevil N. bruchi was reported from Dique Los Sances reservoir in La Rioja Province, Argentina, by Deloach and Cordo (1983). However, they pointed out that Dique Los Sances was not typical of water hyacinth growth in most parts of the world. The lake presented a marginal habitat for the weed so that the added stress caused by N. bruchi provided better control than might occur in the more favourable habitats.

Manoharan et al. (1981) studied the effectiveness of the acridid Gesonula punctifrons (Stal.) and found 55 per cent damage within six months. He suggested that the acridid may be used in conjunction with N. eichhorniae for effective control of the weed.

Wright (1980) reported that liberations of Sameodes albiguttalis (Warren) in Australia began in 1977 and that the moth spread rapidly, causing severe damage to water hyacinth in many locations. The establishment of S. albiguttalis (Warren) in Florida was first reported by Center and Durden in 1981.

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However, Wright (1984) revealed that the effect of the bio agents S. albiguttalis and Acigona infusella on the control of E. crassipes was generally unsatisfactory in Australia. Room (1986) pointed out that eventhough the moths S. albiguttalis and A. infusella were released in 1978 and 1981 respectively in Australia, the former had little effect on E. crassipes and the establishment of the latter was not yet confirmed.

Eventhough many insects were listed as natural enemies of water hyacinth, only a few were reported to be promising. G. punctifrons, S. albiguttalis and A. infusella were not quite successful in controlling the weed, however, N. bruchi was able to control the weed in Argentina.

2.3.3.6 Studies with N. eichhorniae Warner

Deloach and Cordo (1976a) reported that the pupae of the insect were invariably attached to the live roots of water hyacinth which indicated its high degree of host specificity. Deloach (1976) reported that N. eichhorniae was sufficiently host specific for introduction into United States. Single and multiple host specificity tests showed that N. eichhorniae fed and regularly reproduced almost exclusively on E. crassipes (Nagarkatti and Jayanth, 1984).

2.3.3.6.1 Life cycle, behaviour and ecology of N. eichhorniae Warner

Deloach (1975) had given a key for the separation of N. bruchi, N. eichhorniae, N. affinis and Neochetina n sp. O'Brien (1976) revised the New World Sub aquatic genus Neochetina.

Life cycle and biology of N. eichhorniae were described by Deloach and Cordo (1976a). They reported that the insect laid a maximum of 73 eggs per female per day. Stark and Goyer (1983) observed that on an average 2.8 ± 4 eggs were deposited by the insect in 24 hrs.

Fosse (1978b) reported that the insect produced a maximum of 300 and an average of 50 eggs in their life time. Jayanth (1987a) found out that the weevil laid 891 eggs in their whole life period.

Deloach and Cordo (1976a) reported an incubation period of 6 to 9 days and a larval period of 90 days. However Fosse (1978b) found 7-14 days incubation period, 60 days larval period and 14-20 days pupal period, whereas Stark and Goyer (1983) observed 8 days incubation period and 41 days larval period. Jayanth and Nagarkatti (1984) found that 60-80 days are required for the completion of the larval stage.

Stark and Goyer (1983) reported that the average adult longevity was 57.8 ± 9.6 days. However Fosse (1978b) reported that

adults lived upto 280 days, whereas Jayanth (1987a) found that the female weevils lived for 142.2 days while the males lived for 170.4 days.

The intrinsic rate of increase under laboratory conditions was calculated as 0.0422, while generation time of 120.2 days and a doubling time of 16.4 days are also reported (Deloach and Cordo, 1976a). Deloach and Cordo (1976b) observed that the maximum rate of oviposition for N. eichhorniae occurred in October and November. Studies on the deposition of eggs and the dispersal patterns of larvae of N. eichhorniae within water hyacinth shoots showed that the deposition of eggs was influenced by leaf age, while dispersal of larvae was strongly influenced by exposure duration (Center, 1987).

Fosse (1977) reported longest weevil mortality and highest oviposition and feeding at a temperature of 15-35°C. Deloach and Cordo (1976a) were of the opinion that the adult ate a maximum of 86 mm^2 leaf per day and the females of the insect fed 2.8 times as much as males.

The weevils were not generally positively phototropic, but were attracted to mercury lamps in areas with heavily attacked water hyacinth plants in Southern Louisiana in 1980 (Center, 1982). Stark and Goyer (1983) reported that light traps were found unsuccessful as a means of attracting N. eichhorniae and stimulation of adults to fly in the laboratory proved unsuccessful.

The adult sex ratio in the field was 1:1 (Fosse, 1978b; Stark and Goyer, 1983). Perkins (1976) devised a technique for collecting N. eichhorniae from established sites for distribution to other sites. Fosse and Perkins (1977) attributed the kairomone from young growing tissues of water hyacinth for the apparent concentration of the weevils.

Wright and Center (1984) observed a close relationship between the number of adult N. eichhorniae and the number of feeding scars on the water hyacinth leaves. The empirical formula $I = 0.0366S^{0.775}$ (Where I = weevils per plant and S = Feeding scars per lamina) effectively predicted the number of weevils.

The rates of feeding or mortality of N. eichhorniae on E. crassipes leaves excised from plants which were earlier exposed for four weeks to sub-lethal concentrations of Pb, Cd and Cu were not significantly affected by these metals (Kay and Haller, 1986).

From the above part of the review it can be understood that there is a wide variation in adult longevity which ranged from 57 to 280 days. Larval period also varied from 41 to 90 days.

2.3.3.6.2 Field establishment and evaluation of the effects of N. eichhorniae

N. eichhorniae and N. bruchi were introduced into the United States from their native home in South America in 1973. Perkins (1974)

observed that the damage by five adult weevils could kill a medium sized water hyacinth plant in the laboratory in about 10 days. Burkhalter (1975) reported that promising results were obtained in Florida. A substantial reduction in water hyacinth production resulting from the activity of N. eichhorniae, in the form of reduced plant height, weight, root length and number of daughter plants produced, was recorded by Goyer and Stark (1984). Center (1982) found that the effects of the weevil damage were rarely visible as a sudden collapse of the weed population. Subtle changes occurred which were difficult to observe over a short term period. Four years after the release of the weevils, average plant height got reduced from 100 cm to 65 cm. Inhibition of growth of the weed mat was also observed. Peak standing crop was reduced from 2.5 to 1.5 kg (dry weight per m^2). The weed coverage of the study site declined from over 90 per cent in 1974 to about 25 per cent in 1980. Elsewhere, tank grown water hyacinth was severely affected by one month's exposure to N. eichhorniae. Under field conditions, vigour and reproduction of the weed were severely reduced which in some instances proved fatal (Goyer and Stark, 1984). Cofrancesco et al. (1985) conducted a survey of the coverage of the weed before and after the release of N. eichhorniae in Louisiana, U.S.A. They found that the coverage of 1.1 million acres in 1975 was reduced to 0.3 million acres by 1980. Center and Durden (1986) compared the weed populations, weevil populations and plant damage in Florida and found that standing crop and shoot size were inversely related to the number of weevil galleries and proportion of lamina consumed by adults.

The observation suggested that biological control could be effective if a minimum time period was allowed. Plant size and weevil density determined the length of this interval.

Later, the expectations raised by the weevil in controlling water hyacinth dwindled as reported by Center (1985). He found out that the natural enemies of water hyacinth often do not kill the shoots, but cause varying degrees of leaf damage. Leaf life tables showed that the damage caused by S. albiguttalis and the two species of weevils resulted in an overall 34 per cent reduction in leaf longevity. Thus even without direct shoot mortality, a degree of control was achieved. But he opined that the damage caused by N. eichhorniae was constant and effective.

Releases of N. eichhorniae were commenced in Australia in October 1975. Wright (1980) reported that with the introduction and release of N. eichhorniae, death followed by collapse of the floating mass of the weed occurred. Forno (1981) studied the effects of attack by the weevil N. eichhorniae on floating, anchored and rooted plant forms of water hyacinth. She found that the insect attack reduced the petiole diameter and leaf density of floating plants and petiole length and standing crop of those which were rooted. Anchored plants showed greater overall tolerance to insect damage. Later in 1982 Wright observed that N. eichhorniae caused detectable damage to water hyacinth in Australia.

However, further reports from Australia pointed out that the weevil was not successful in controlling the weed. Wright (1984) emphasized the need for further research in biocontrol of E. crassipes in Australia since the effects of introduced agents N. eichhorniae, S. albiguttalis and A. infusella proved to be generally unsatisfactory. Room (1986) reported that the weevil N. eichhorniae gave moderate control in tropical regions, but was less effective further south.

N. eichhorniae and N. bruchi were released in Sudan from 1978 onwards. The weevils became established and were found dispersing in the White Nile system (Irving and Bashir, 1982). Later Bashir (1984) recorded a more abundant and wide distribution of N. eichhorniae than N. bruchi in White Nile system. Bashir and Bennet (1985) observed a drastic reduction in the growth rate of the weed following the introduction and establishment of N. eichhorniae, N. bruchi and S. albiguttalis in Sudan. N. eichhorniae was released in Fiji in 1978 and the weevil established in all the released sites, but damage to plants was not significant as reported by Singh et al. (1982).

In an evaluation made in Argentina of the potential of six arthropods as agents for biological control of water hyacinth, the three agents A. infusella, N. bruchi and N. eichhorniae were effective in this order (Deloach, 1975).

N. eichhorniae was introduced into India in 1982 under the All India Coordinated Research Project on Biological control of Crop

pests and Weeds. Field releases of N. eichhorniae initiated in March 1983 after host specificity tests under quarantine conditions conclusively proved its safety to cultivated crops (Nagarkatti and Jayanth, 1984). They further observed that the larvae developed from eggs laid by 9 females during a five day period on three plants caused the complete collapse of the mother plants as well as daughter plants. N. eichhorniae was established in Bellandur tank of Bangalore, four months after the initial release. The insect population had increased from 1.05 per plant to 5.4 adults per plant in about six months, while the petiole length was reduced from 57 cm to 32 cm in 14 months period. By June 1986, the coverage of the weed was reduced by 50 per cent (Jayanth, 1987b). Later it was noted that more than 95 per cent infestation by the weed was cleared within 32 months after the release of N. eichhorniae in a 20 ha tank at Bangalore. Fresh plants emerging were also suppressed by the insect (Jayanth, 1988).

2.3.3.6.3 Parasitism/predation and diseases.

Deloach and Cordo (1982) recorded that 40-60 per cent population of N. eichhorniae were infected by nematodes (Metaparasitylenchus sp.) while 7-22 per cent were infected by a microsporidian (Nosema sp.) and 4 per cent infested with mites (Histiostoma sp.) and by various arthropod predators in Argentina.

The above part of review elucidates the establishment and performance of N. eichhorniae in different countries. The insect was established in all the released countries and the initial performance was

hopeful; but later reports showed that only a percentage of control was achieved, except at Bangalore. However several workers suggested that biological control of the weed could be effective if a minimum time period was allowed.

2.3.3.7 Possibilities of integrated control involving N. eichhorinae

N. eichhorniae and the fish White amur (Ctenopharyngodon idella Valencieunes) were used in combination to test their effect on water hyacinth, contained in plastic pools. The combination reduced the growth of the weed by 20-38 per cent (Fosse et al., 1976).

Manoharan et al. (1981) suggested that the acridid G. punctifrons in conjunction with N. eichhorniae might bring about water hyacinth control.

Interaction between the weevil N. eichhorniae and the water hyacinth mite O. terebrantis was studied by Fosse (1978b). The study indicated that the weevils laid more no. of eggs and fed more in the presence of the mite, possibly due to the release of the kairomone from water hyacinth tissue. O. terebrantis was found to have a synergistic relationship with N. eichhorniae. Combinations of N. eichhorniae and O. terebrantis reduced the size and density of the weed significantly when compared to reduction due to either arthropod alone.

Charudattan et al. (1978) isolated several parasitic fungi, including the pathogen of water hyacinth. A. zonatum was isolated from

the weevil and mite infested water hyacinth plants. They found that A. zonatum incidence was related especially to damage by adult mites. The combined effect of arthropods and disease led to root and crown rot under severe conditions. They recommended an integrated approach using insects and pathogens for controlling the weed. Galbraith (1987) investigated the possibility of developing A. zonatum as a micoherbicide to supplement the arthropod bioligical control programme in Australia. He observed that feeding by the weevil N. eichhorniae increased infection by A. zonatum. It was also found that the spores of A. zonatum were spread to the new loci by the weevils by carrying them on their feet and through the digestive system. The combined damage by the weevil and the fungus was high. He suggested that the role of A. zonatum was probably its ability in exerting a chronic stress in plants already under attack by arthropod biological control agents. Center et al. (1982) studied the combined effect of N. eichhorniae and a growth retardant EL-509 on water hyacinth. They found that the growth retardant was ineffective without weevils and the weevils appeared to be more effective when used in combination with the retardant. The combined effect was additive.

Haag (1986a) reported that 2,4-D caused no significant mortality to N. eichhorniae though the weevils consistently migrated from 2,4-D sprayed, to fresh plants in the experimental tank. Effective control of water hyacinth using Neochetina weevils and limited herbicide application was tried by Haag (1986b). A small weed infested pond with low densities of the weevils was used for the experiment. A floating barrier was placed across one end of the pond, enclosing

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20 per cent of plants (reservoir area). The remaining plants were gradually sprayed with 2,4-D (2.2 kg/ha) in monthly increments of 25 per cent, beginning in August starting from the end of the pond, farthest from the reservoir area. By February, all sprayed plants had disappeared and weevil densities were very high on the reservoir plants. These plants showed signs of extensive damage from heavy weevil feeding. All the water hyacinth plants were completely destroyed by the month of May.

Materials and Methods

MATERIALS AND METHODS

The bio-agent N. eichhorniae is being used in many parts of the world for controlling the weed E. crassipes. For the successful use of the bio-agent, its biology, the nature and extent of damage caused to the weed, and the dispersal pattern of the insect were studied. In this chapter the materials and methods used for the study are described.

3.1 Biology

Studies on the biology of N. eichhorniae were carried out under laboratory conditions at the insectary of the All India Co-ordinated Research Project on Biological control of Crop Pests and Weeds, College of Horticulture, Vellanikkara during 1987-'89. The insect was reared on water hyacinth plants maintained in cement concrete tanks.

Pupae of the insect were collected from culture tanks and when adults emerged, they were sexed. Eight pairs of freshly emerged adults were used for the study. Individual pairs were released in separate plastic jars (11 x 8 cm) with wire-mesh windows on the lids to facilitate aeration. A water hyacinth leaf retaining 2 cm of petiole was introduced into each jar with 1 cm of water at the bottom. The exposed leaves were removed every day and fresh ones were introduced. The collected leaves were then dissected out under a stereo-microscope and the eggs were transferred for further studies.

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3.1.1 Egg

The eggs from the dissected leaves were transferred to a moistened filter paper kept in paired petridishes. Incubation period and the hatching percentage were recorded. Sample size is 100.

3.1.2 Larva

Newly hatched larvae were introduced into punctures made with forceps in petioles of water hyacinth plants grown in concrete tanks (35 cm diameter). These tanks were covered with nylon net to prevent external infestation. The plants were periodically dissected in order to obtain larvae, which were measured to fix the instars. The larval period was also recorded.

3.1.3 Pupa

The pupae along with the plants were placed in water filled museum jars (10 x 10 x 20 cm) and kept undisturbed until the adults emerged, and the pupal period was recorded. Sample size is 10.

3.1.4 Adult

Emerging adults were collected and sexed. Ten pairs of freshly emerged adults were used for the study as described in para 2.1. The exposed leaves were removed every day and fresh ones were introduced.

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3.1.4.1 Courtship behaviour

The courtship behaviour during day and night was studied and recored.

3.1.4.2 Pre-ovipositional period

The introduced leaves were dissected out on the next day under a stereo- microscope and checked for the eggs. The pre-ovipositional period was calculated.

3.1.4.3 Ovipositional period

The introduced leaves were dissected out and the ovipositional period was computed.

3.1.4.4 Fecundity

The number of eggs laid per female per day was noted for the whole ovipositional period and the fecundity were recorded.

3.1.4.5 Adult longevity

The dates of death of the adult insects were noted and the longevity of male and female weevils were calculated.

3.2 Morphology

Measurements of the size of adult weevils, pupae, larvae of different instars and eggs were taken using a micrometer. Permanent slides of

legs, antennae, mouth parts, wings and the genitalia were prepared.

3.2.1 Preparation of slides

The required parts of the insect were dissected, transferred into glass tubes (75 x 15 mm) containing five per cent potassium hydroxide and boiled for five minutes. The tissues were removed and the specimens were transferred to glacial acetic acid and were retained for 3 min for neutralising the excess alkali. The specimens were then introduced into Carbol-Xylol (1:3) and kept for 12 h. Clearing of the specimens before staining was done by transferring them to Xylol for 15 min. Genitalia and mouth parts were stained using acid fuchsin. The specimens were then mounted using Canada balsam, labelled and stored in slide trays.

3.2.2 Measurements

The measurements of various life stages and organs of the adult insect were recorded. The details of length and width of various organs and stages recorded are presented below: Sample size taken is 10nos.

Stage/organ	Length	Width
1. Egg	End to end	Across the widest area
2. Larva	Anterior margin of head to anal margin	Across the widest area
a) Head capsule	n.m.	Maximum width across the middle portion
b) Mandible	Proximal end to distal end	n.m.

3. Pupa	End to end	Across the widest area
4. Adult	Anterior tip of snout to apex of elytra along the mid dorsal line	Across the widest area of the closed elytra
a) Antenna	Base of scape to apex of club	n.m.
Scape	End to end	n.m.
Funiculus	End to end	n.m.
Club	End to end	n.m.
b) Rostrum	Base to apex	Across the narrowest portion
Position of antenna	Antennal socket to tip of rostrum	n.m.
c) Prothorax	Base of rostrum to posterior margin of prothorax	n.m.
d) Meso and Metathorax	Anterior margin of mesothorax to posterior margin of metathorax on the ventral side	n.m.
e) Abdomen	Posterior margin of metathorax to tip of last anal segment	n.m.
f) Elytra	Base to apex of elytra	Across one-third distance from the anterior margin
g) Hind wing	Base to tip	Across the widest area
h) Legs	Coxa to end of claw	n.m.
Segments	End to end	n.m.

n.m = not measured

3.3 Presence of natural enemies

Samples of natural population of N. eichhorniae were collected from water hyacinth infested water bodies at Trichur, nine km away from the project centre. The weevils were examined in the laboratory for the presence of mites and microbes. For detecting the presence of micro orgnisms, adults were ma cerated in a drop of sterile water on a microscopic slide, from which a droplet was transferred to a second slide and a cover glass was placed over it. The slide was then examined at 400x magnification. The sample size was 50 Nos. of insects.

Predators used in feeding tests were collected from water hyacinth, placed in petridishes with moist filter paper at the bottom, and held at room temperature in the laboratory. Eggs and small larvae were placed in the containers and the rate of feeding was observed.

3.4 Dispersal studies

Dispersal studies were conducted in plastic pools of 3 m dia. each. Four to six week old Eichhornia plants were used for the study. The plastic pools were filled with water and completely filled with Eichhornia plants. Fabric paint was used for marking the weevils. Marked adult weevils were then released at a particular marked point. The plants around the released point were daily examined. The distance travelled and the direction of movement were recorded. Light trap was used to study the phototropism of the weevils.

3.5 Nature of damage

Experiments on the feeding damage was conducted in R.C.C. tanks (35 cm diameter) using completely Randomised Block Design. Eichhornia under both free floating and rooting conditions were used for the trial. Three replications were maintained for each growing condition. For the rooting type of growth, 2/3rd portion of the tanks was filled with soil, over which a layer of clayey soil was placed and water filled to simulate field condition. Fresh cowdung was added in all tanks @ 40 g/litre.

Five plants each of 3-4 weeks old clumps were used for the study. Field collected adult weevils @ 4, 6, 8, 10 and 12 per clump, keeping the sex ratio equal, were released in the tanks. Three insect-free control tanks were kept in each type of growth as checks. Top of the tanks were covered with nylon net fitted on MS rod frame to confine the weevils to the tank. Water level in the tanks was kept constant by addition of water regularly.

Length of root, length of the petiole, length and width of the pseudolamina of five randomly selected plants from each tank were observed at fortnightly intervals. Total number of plants, leaves and total weight of plants, after taking them out of the water and shaking three times uniformly, were also noted. For measuring leaves, the longest available leaf was always used, and unopened and decaying ones were not included while counting. For counting the number of plants, daughter plants that had not fully separated from mother plants were not included.

The temperature and relative humidity during the period of study fluctuated between 22.2 to 37.1°C and 27-75 per cent respectively.

3.6 Adult behaviour

3.6.1 Feeding preference

For finding out the feeding preference by adults on the plant parts, samples of leaves along with petiole were collected from the field, and the number of feeding scars on the dorsal and ventral sides of the lamina and petiole were counted.

3.6.2 Variations in feeding during day and night

The experiment was carried out in the laboratory using circular plastic containers (11 x 8 cm) with ventilated lid. 1 cm level of water was maintained in the jars. In these jars, water hyacinth leaves retaining 2 cm of the petiole were placed. Adult weevils were released in these jars, and ten replications were maintained. Feeding damage was measured by placing leaves on the graph paper and counting the number of squares.

Variation in feeding was studied by changing the leaves after every photo and scoto phase.

Males and females were separately released in the containers to study their variation in feeding.

3.6.3 Variation in oviposition during day and night

The experiment was carried out in the laboratory using circular plastic jars (11 x 8 cm) with ventilated lid. One cm level of water was maintained in each jar. Leaves of water hyacinth retaining 1 cm of the petiole were introduced in each jar and paired adults were released. Twenty replications were maintained. Leaves were removed after every photo and scoto phase. Later, the leaves were dissected out to count the number of eggs.

3.7 Estimation of field population

Population estimation study was conducted using the infested Eichhornia plants in RCC aquaria and also from Kokkalai, 9 km away from the Project Centre at Vellanikkara. The number of feeding marks on the leaves was tried as a method of prediction of population intensity of adult weevils. Plants were selected randomly, and the number of feeding marks on upper and lower sides of the lamina of the second youngest leaf was counted and recorded. The second youngest leaf was selected based on report by Wright and Center (1984). The plants were examined to get the number of weevil per plant, and the data gathered were analysed statistically.

Statistical analysis

For comparison of treatments with respect to weight of Eichhornia, number of plants per tank, number of leaves per tank,

petiole length, laminar length, laminar width at different population loads, and also for comparing the dimensions of different organs of the insect, the analysis of variance technique was made use of (Panse and Sukhatme, 1978).

Results

RESULTS

Results of the studies on biology, morphology, nature of attack and dispersal of the insect N. eichhorniae are presented in this chapter.

4.1 Biology

The duration of different life stages of the insect reared under controlled conditions is presented in Table 1.

4.1.1 Eggs

Eggs were laid beneath the epidermis of leaves, petioles, or ligules at the base of the petioles of water hyacinth. The insect made cavities with its mandibles and laid eggs at the rate of one per hole. Eggs were occasionally deposited on the leaf surface, in old feeding scars and on the base of the rearing chamber under laboratory conditions. The weevil preferred lower leaf surface for egg laying. Eggs were creamy-white in colour. Incubation period varied from six to nine days, the average being 6.6 days and the hatching percentage was 93.2 at temperature 29.5°C and relative humidity 66 per cent.

4.1.2 Larva

After eclosion, the newly hatched larva bored towards the base of the petioles. The second and third instars were found at the

base of the petioles or in the crown where they formed tunnels. The three instars were completed in about 8-10, 13-16 and 13-17 days respectively. Total larval period varied from 34-44 days at temperature 30.7°C and 67.1 per cent relative humidity.

4.1.3 Pupa

Full grown larvae moved out of the tunnels in the crown and reached the upper root zone, just under the surface of water. They cut of the lateral rootlets and formed a ball like cocoon around themselves. This cocoon was found attached to one of the roots. At the point of attachment, the larva made a small lesion on the root. The pre-pupal period lasted for 3-4 days. The pupae were not found to emerge when they were detached from the roots at an early stage of development. Pupae in an advanced stage of development could emerge from the cocoon, even if they were removed from the roots. Pupal period ranged from 15 to 20 days, the average being 16.6 days at 28.4°C temperature and 41.1 per cent relative humidity.

4.1.4 Adult

The emerging adults were metallic brown in colour which later turned dark brown or grey mottled with brown. The adults congregated within the central unfurled leaf and scraped the epidermis resulting in distinct markings on the leaves and petioles. Adults also congregated at the base of the petioles. They were nocturnal in habit. The weevil was having a characteristic waxy coating over the body

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Table 1 Duration of different life stages of N. eichhorniae reared under controlled conditions

Sl. No.	Period (days)				
	Egg	Larval	Pupal	Adult male	Adult female
1	6	36	15	129	80
2	7	35	20	134	112
3	6	39	19	142	31
4	8	43	14	149	77
5	6	34	16	157	75
6	6	38	19	162	46
7	9	40	17	177	60
8	6	40	15	211	115
9	6	42	16	230	127
10	6	44	15	232	130
Mean	6.6	39.1	16.6	172.3	75.3

surface. Adult had the habit of feigning death on disturbance. The females were relatively larger than the males. Adult females lived for a period of 75.3 days in the laboratory (range 31-130 days) and adult males for 172.3 days (range 129-232 days) at 28.0 ± 4.6°C temperature and 53.33 per cent relative humidity.

4.1.5 Courtship behaviour

The insect mated periodically during the day and night. The frequency of mating during night was higher than that during the day. During mating, the female carried the male on her back and she walked slowly with her antennae moving. This lasted for nearly 5-10 minutes after which the male stopped dorsal riding and started posterior riding. The actual genital insertion occurred during this phase which lasted 20-25 min.

4.1.6 Pre-ovipositional period

Pre-ovipositional period recorded ranged from 2 to 9 days, the average being 4.9 days.

4.1.7 Ovipositional period

The ovipositional period prolonged till the death of the insect.

4.1.8 Fecundity

The total number of eggs produced during the whole life

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Table 2 Longevity and fecundity of N. eichhorniae under laboratory conditions

Sl. No.	Adult longevity (days)	Eggs laid by adult females (Number)		
		Total	Mean	Maximum recorded per day
1	80	465	5.81	21
2	112	568	5.07	13
3	31	186	6.00	16
4	77	357	4.63	13
5	75	407	5.42	20
6	46	313	6.80	18
7	60	404	6.73	20
8	115	816	7.09	18
9	127	639	5.03	14
10	130	771	5.85	15
Mean	75.3	462.5	5.85	16.8

FIG. 1 Egg production of N. eichhorniae in relation to age

Table 3 Variation in egg production of *N. eichhorniae* under controlled conditions during day and night

Sl. No.	Number of eggs laid during		Sl. No.	Number of eggs laid during		CD (0.05)
	Day	Night		Day	Night	
1	0	0	11	3	2	
2	2	4	12	4	11	
3	0	0	13	0	0	
4	0	2	14	0	3	
5	0	2	15	6	2	
6	2	4	16	0	11	
7	3	4	17	2	0	
8	2	2	18	1	7	
9	6	6	19	5	7	
10	0	0	20	2	4	
			Mean	1.068 (1.034)	2.229 (1.493)	0.644

$\sqrt{x}$ Transformation of data was made before analysis

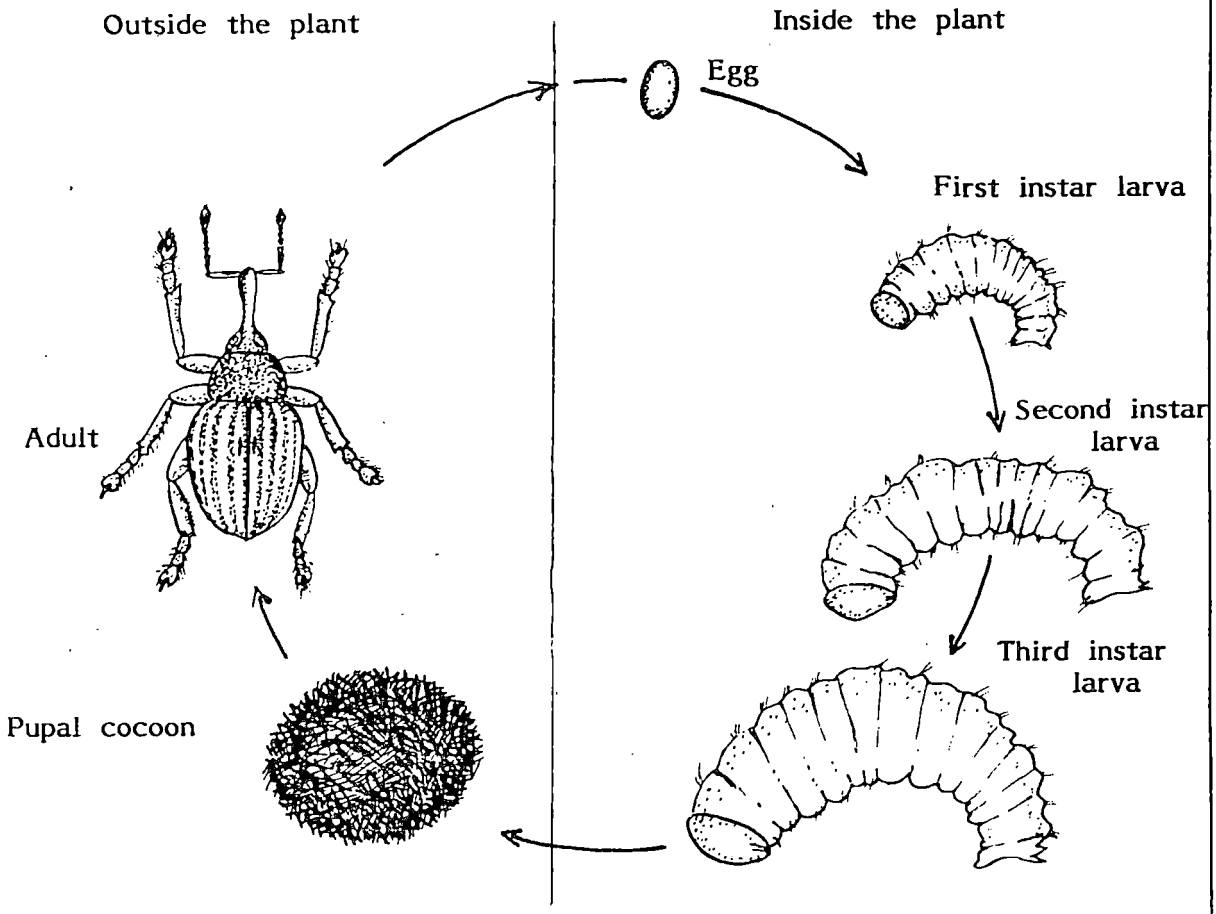


FIG. 2 Life cycle of N. eichhorniae

period ranged from 186 to 816 (mean 462.5 eggs) (Table 2). Maximum number of eggs produced by a single female per day was 21 and the mean egg production per day for the whole life period was 5.85. The mean daily egg production peaked at 12.5 on the 16th day after emergence. (The mean weekly egg production is presented in Fig.1). The weevil laid 100 per cent more number of eggs during night (2.22 eggs) compared to that (1.06 eggs) during day (Table 3). But the variation was not statistically significant.

4.2 Morphology

Measurements on the size of immature stages of N.eichhorniae are presented in Table 4.

4.2.1 Egg

Eggs were elongate, oval with a mean length of 0.77 mm and width 0.42 mm (Fig.3A). Body segmentation of the first instar larva could be observed in a mature egg.

4.2.2 First instar larva

Freshly emerged larvae were creamy-white with yellowish-orange head. They were apodous. Enlarged swellings with setae (small hairs) were present in the place of legs (Fig.4A). The posterior end of the abdomen was blunt and a pair of spur like spiracles projecting upward, were present on the last abdominal segment. Body segmentation

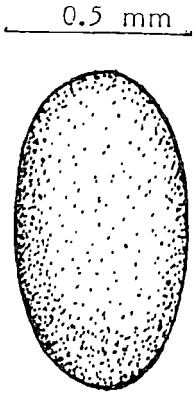


FIG. 3A Egg

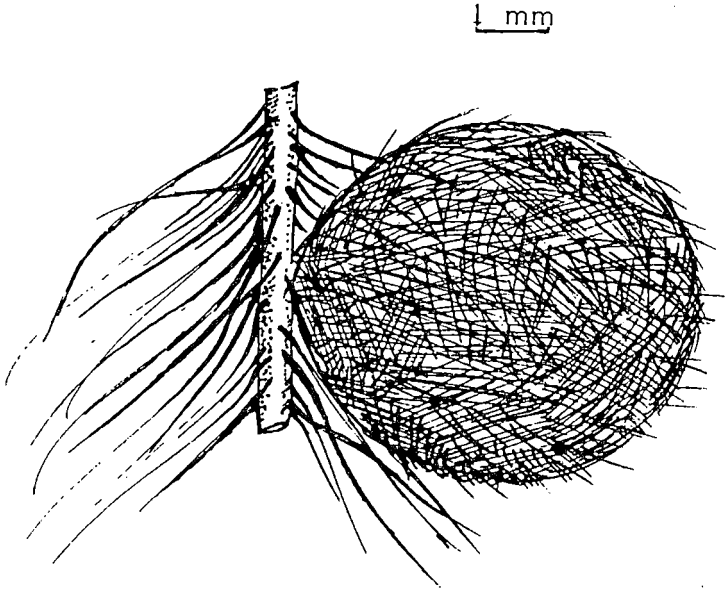


FIG. 3B Pupal cocoon

was not quite distinct. The mean length was 2.38 mm and width was 0.448 mm. The head capsule, on an average, measured 0.3 mm and the reddish brown mandibles had an average length of 0.155 mm.

4.2.3 Second instar larva

They were more active, and yellowish-white. Trailing setae were fewer in number (Fig.4B). Their mean body length and width were 6.26 and 0.91 mm respectively. Mean head capsule width was 0.488 mm and mean mandible length was 0.21 mm.

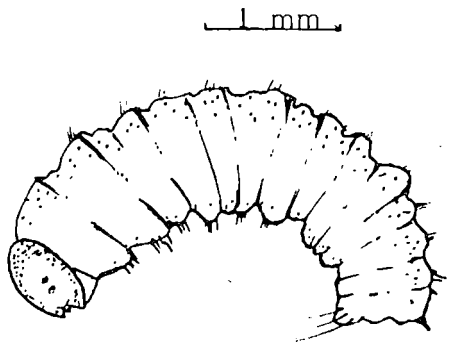
4.2.4 Third instar larva

Third instar larvae were 'C' shaped and very active. The setae on the body were very few in number (Fig.4C).

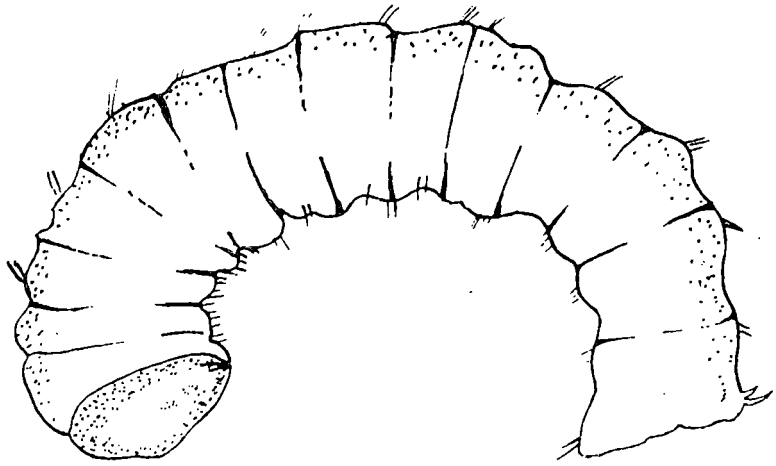
Their mean body length was 9.37 mm and width 1.41 mm. Mean head capsule width was 0.693 mm and mean mandible length 0.265 mm.

Analysis of variance revelaed that head capsule width of first (0.3 mm) and second (0.488 mm), second and third (0.69 mm) and first and third instars varied significantly (Table 5).

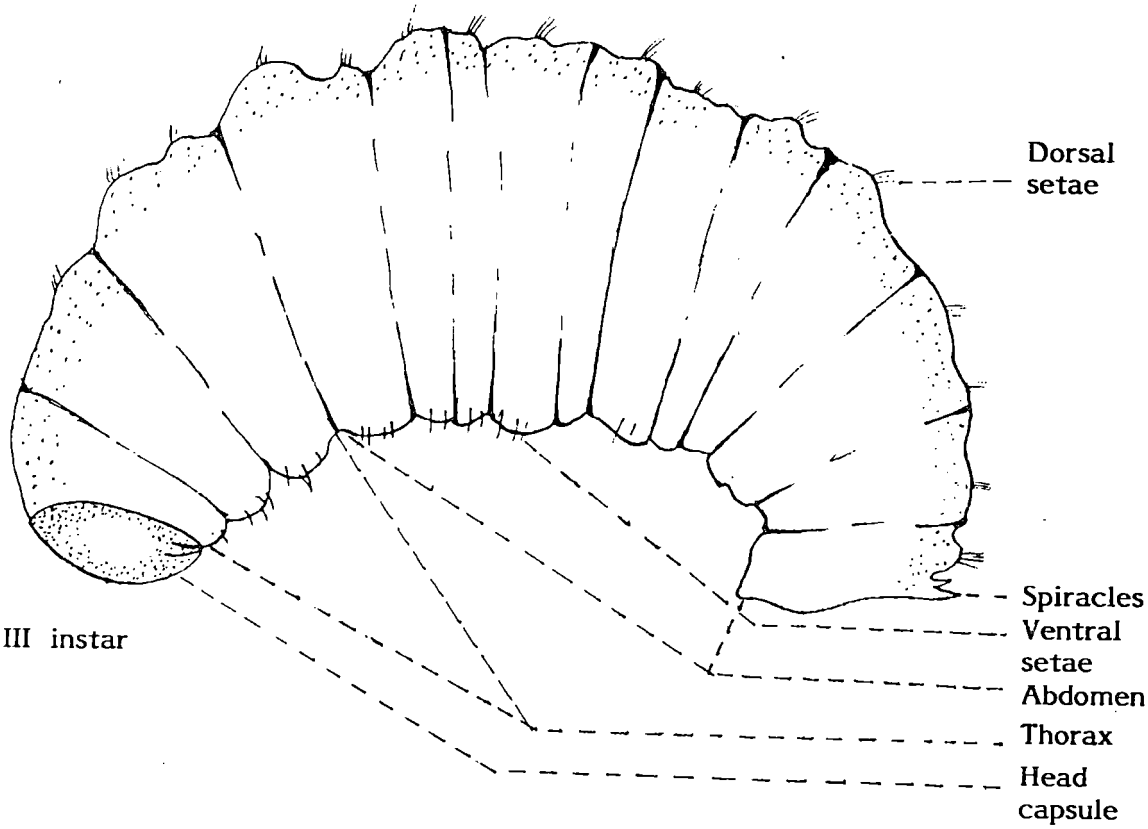
Analysis of data on mandible length also showed conspicous difference between the three instars.



A. I instar



B. II instar



C. III instar

FIG. 4 Larval instars of N. eichhorniae

Table 4 Mean size of immature stages of N. eichhorniae

Stage	Length (mm)			Width (mm)		
		Range			Range	
	Mean	Min.	Max.	Mean	Min.	Max.
Egg	0.77	0.66	0.87	0.42	0.34	0.48
Larva						
I instar	2.38	1.40	3.50	0.448	0.315	0.575
II instar	6.26	4.02	9.09	0.91	0.66	1.23
III instar	9.37	6.84	12.39	1.41	1.12	2.20

Table 5 Measurements of head capsule width and mandible length of N. eichhorniae

	Width of head capsule (mm)			Length of mandibie (mm)		
		Range			Range	
	Mean	Min.	Max.	Mean	Min.	Max.
1st	0.3	0.25	0.39	0.155	0.06	0.16
2nd	0.488	0.40	0.55	0.21	0.155	0.225
3rd	0.693	0.63	0.78	0.265	0.24	0.315
CD (0.05)	0.0427			0.0209		

4.2.5 Pupa

Pupa was more or less spherical in shape and was attached to the living roots of the plant (Fig.3B). The size (dia) of pupal case averaged 6.4 mm (5.5-7 mm).

4.2.6 Adult

Measurements of different organs of the insect are presented in Table 6.

Freshly emerged adults were metallic brown, which later turned to dark brown. Average length and width of male and male insects were 4.55 and 2.08 mm, and 5.2 mm and 2.27 mm respectively. It was found that the females were distinctly longer (Fig.5B) than the males (Fig.5A). Width also showed significant difference between sexes.

4.2.6.1 Rostrum

Rostrum of the male was thick, weakly curved, wider from the point of antennal socket to the apex, and curved downwards beyond antennae. It was shiny dorsally from the point of antennal socket to the apex. Suprascrobal groove was present.

Rostrum of the females was larger than that of males. It was larger, uniformly curved. Rostrum was shiny and glabrous from a short distance in front of the eye to the apex. Suprascrobal groove was more distinct in female than in male.

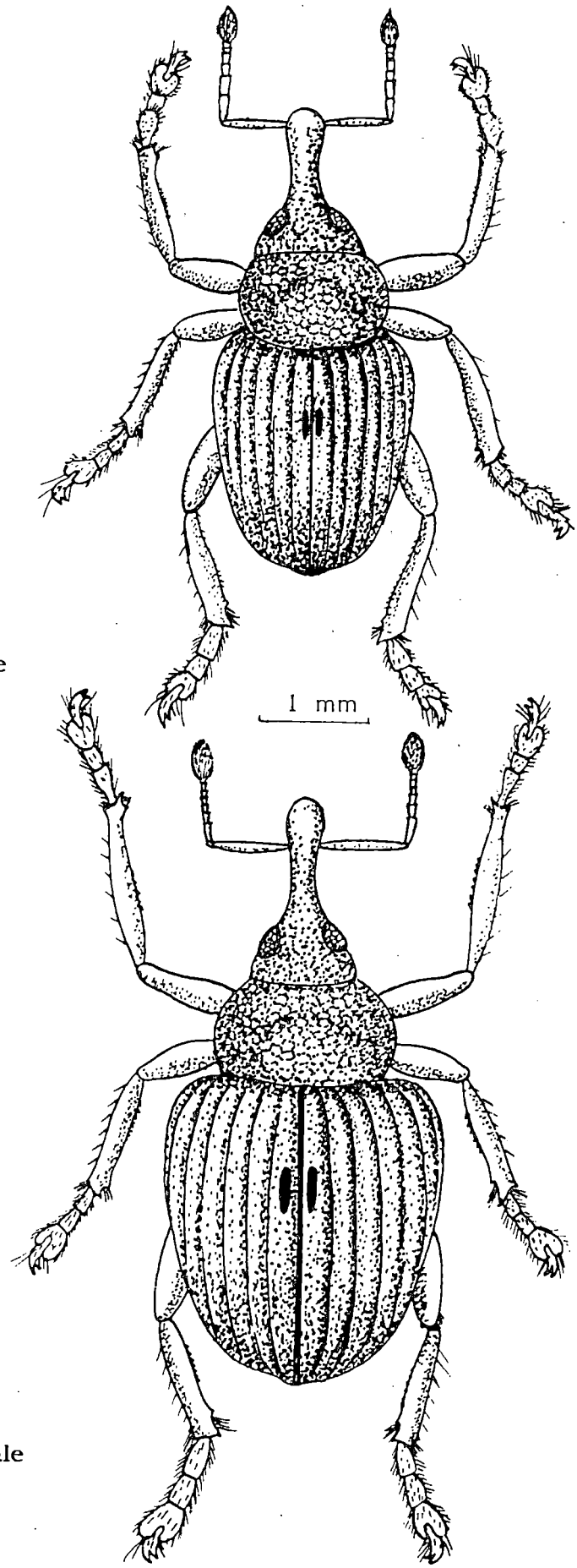


FIG. 5 Adult male and female of N. eichhorniae

The female rostrum was found to be significantly longer (1.25 mm) as compared to males (0.997 mm). Mean rostrum width of the female (0.29 mm) and male (0.25 mm) however, did not differ significantly.

The antennal socket on the rostrum was found to be an important character by which the males and females of the insect could be distinguished visually. In males, the average distance between the antennal socket and the tip of rostrum was 0.259 mm where as in females it was longer (0.487 mm) and the difference was statistically significant.

4.2.6.2 Head

Head was convex and basally clothed with dense yellow hydrofuge scales, and the frons was flat, lacking fovea. The eyes were slightly oval and situated towards the base of the rostrum.

Mouth parts were enclosed in the terminal aperture of rostrum and were much reduced in size. Only the mandibles were visible externally.

The mandibles were hard and reddish brown in colour, 0.2 mm long, 0.15 mm wide with three curved denticles (Fig.6A).

The maxillae were three lobed, cardo short, stipes with prominent notch having a massy palps which was three segmented. Lacinia possessed a short tooth like processes (Fig.6C).

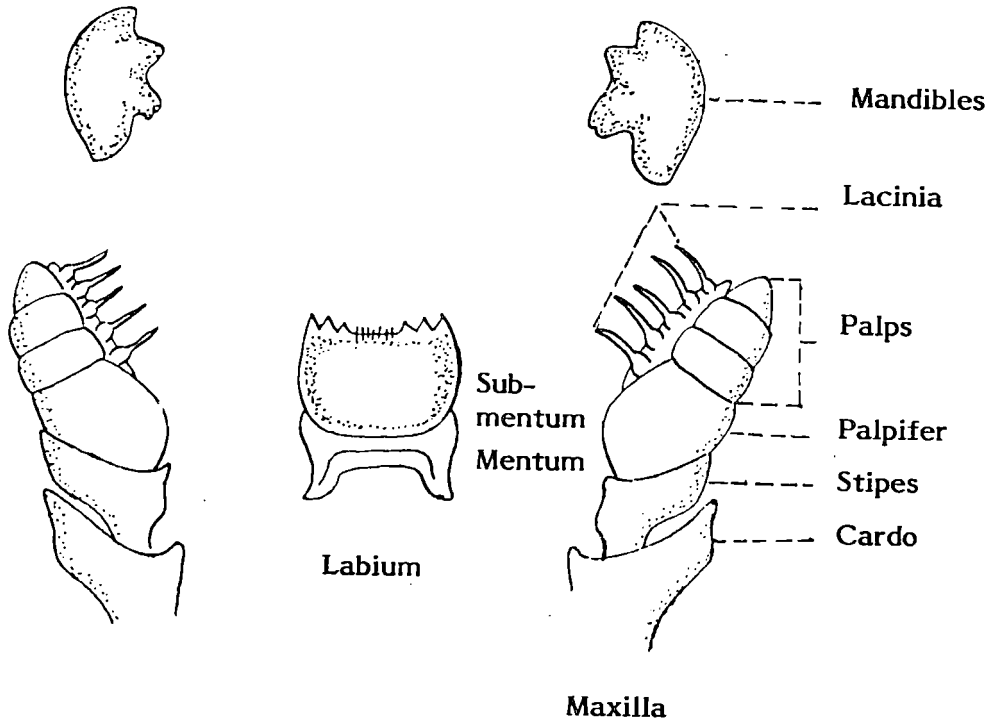


FIG. 6 Mouth parts of N. eichhorniae

The labium consisted of a sub-mentum which was broad, holding a 'U' shaped mentum (Fig.6B).

4.2.6.3 Antenna

Antennae were reddish-brown, inserted at the apical 1/4th region of the rostrum in males and slightly in front of middle region in females.

Scape was elongate, slender towards the base, and swollen apically.

Funiculus was six segmented with the basal segment swollen, bearing pubescence at the apex, and the second segment being swollen and elongate. The other four segments were more or less equal in length. The fifth and sixth segments were finely and densely pubescent. Average length of funiculus was 0.6110 mm.

The club was elongate oval shaped with fine pubescence, having a length of 0.35 mm.

The total length of male antenna (Fig.7A) was 1.69 mm while that of the female (Fig.7B) was 1.92 mm. The antenna was significantly longer in females as compared to the males.

4.2.6.4 Prothorax

Prothorax was weakly constricted apically with punctures on sides and notum. Pronotum was broader than long. Length of male

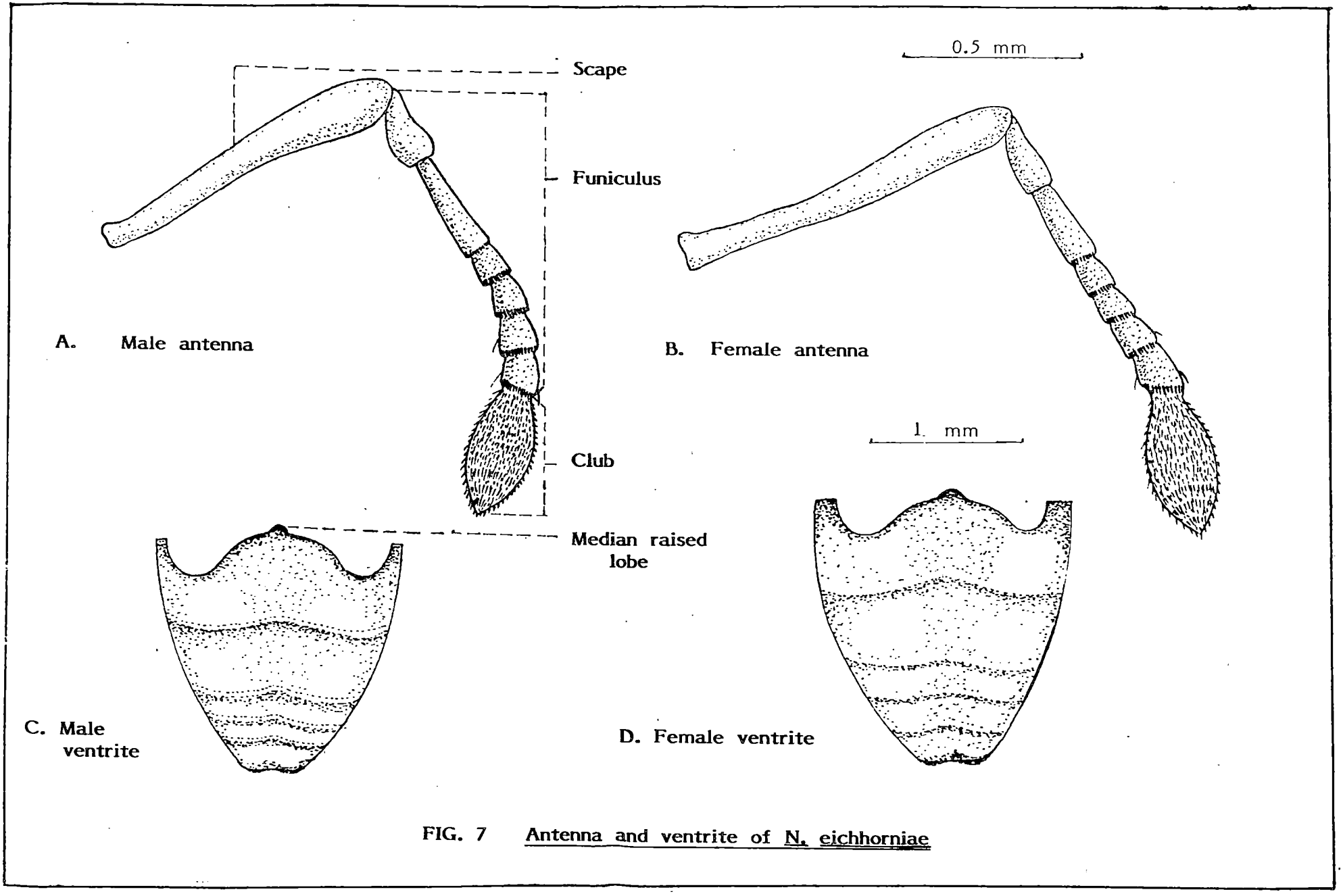


FIG. 7 Antenna and ventrite of N. eichhorniae

Table 6 Measurements of different organs of the insect N. eichhorniae

Part of the insect measured	Length/ width	Measurements (mm)						CD (0.05 level)
		Male			Female			
		Mean	Range		Mean	Range		
(1)	(2)	(3)	(4)		(5)	(6)		(7)
Adult	L	4.55	3.91	- 4.75	5.2	4.91	- 5.81	0.425
	W	2.08	1.916	- 2.25	2.27	2.166	- 2.37	0.072
a. Antenna	L	1.691	1.612	- 1.75	1.92	1.777	- 2.002	0.1074
(i) Scape	L	0.8062	0.8	- 0.825	0.89	0.08	- 0.925	a
(ii) Funiculus	L	0.5795	0.5625	- 0.5875	0.6425	0.602	- 0.667	a
(iii) Club	L	0.305	0.25	- 0.375	0.395	0.375	- 0.425	a
b. Rostrum	L	0.998	0.885	- 1.074	1.258	1.08	- 1.33	0.1156
(i) Antennal socket to tip of rostrum	W	0.260	0.226	- 0.282	0.292	0.25	- 0.33	0.0415
	L	0.2592	0.188	- 0.338	0.487	0.467	- 0.583	0.0745
c. Prothorax	L	1.045	0.916	- 1.166	1.113	0.999	- 1.166	0.1229
d. Meso and Metathorax	L	1.108	1.00	- 1.1669	1.1783	1.084	- 1.25	a
e. Abdomen	L	1.508	1.416	- 1.666	1.629	1.555	- 1.7	0.0986

(Contd.)

Table 6 (contd.)

(1)	(2)	(3)			(4)	(5)	(6)			(7)
f. Elytra	L	2.844	2.74	-	2.962	3.229	3.07	-	3.332	0.1569
	W	1.192	1.148	-	1.22	1.311	1.296	-	1.407	0.0934
g. Hindwing	L	6.4	6	-	6.75	7.078	6.5	-	7.625	a
	W	2.025	1.75	-	9.525	2.06	2.0	-	2.125	a
h. Legs										
a) Total length										
(i) Foreleg		3.641	3.409	-	4.06	4.005	3.925	-	4.22	0.1264
(ii) Midleg		3.792	3.486	-	4.02	4.158	4.075	-	4.275	
(iii) Hindleg		3.983	3.90	-	4.06	4.443	4.252	-	4.635	
b) Coxa	L									
(i) Fore coxa		0.435	0.375	-	0.5	0.485	0.45	-	0.5	0.0372
(ii) Mid coxa)		0.375	0.35	-	0.4	0.425	0.375	-	0.45	
(iii) Hind coxa		0.320	0.3	-	0.325	0.325	0.3	-	0.35	
c) Femur	L									
Fore femur		1.265	1.25	-	1.3	1.48	1.425	-	1.55	0.0626
Mid femur		1.3	1.25	-	1.35	1.485	1.45	-	1.6	
Hind femur		1.39	1.325	-	1.475	1.55	1.425	-	1.525	
d) Tibia	L									
Fore tibia		1.14	1.1	-	1.2	1.405	1.375	-	1.45	0.0549
Mid tibia		1.065	1.05	-	1.075	1.435	1.35	-	1.5	
Hind tibia		1.345	1.25	-	1.375	1.445	1.4	-	1.5	

L = Length W = Width a = Not analysed statistically

prosternum was 1.03 mm which was shorter than that of the female (1.11 mm).

Prosternum was deeply indented, trituberculate behind coxae, with three tubercles almost equal in size. The tubercles were round and distinctly separated from coxae.

4.2.6.5 Meso and Metathorax

Meso and Metathorax fused together, with notum covered by the elytra.

4.2.6.6 Legs

Coxae were clothed with hydrofuge scales; fore-coxae large, strongly globose, mid coxae large, much less globose, and the hind coxae small, transverse and nearly flat. Fore coxae longer (0.455 mm) than mid (0.4 mm) and hind (0.32 mm) coxa (Table 6).

Trochanter was short and triangular with a single hair like process on the inner region.

Femur was narrow basally and wide at about the middle and with a slight notch at sub-apical region. It was clothed with dense agglutinate scales. The hind femur was longer (1.43 mm) than that of the other two legs (mid 1.42 mm, fore 1.37 mm) (Table 6).

Tibia was long and slender with slightly bulged mid portion. It was clothed on its inner margin with hydrofuge scales. The outer

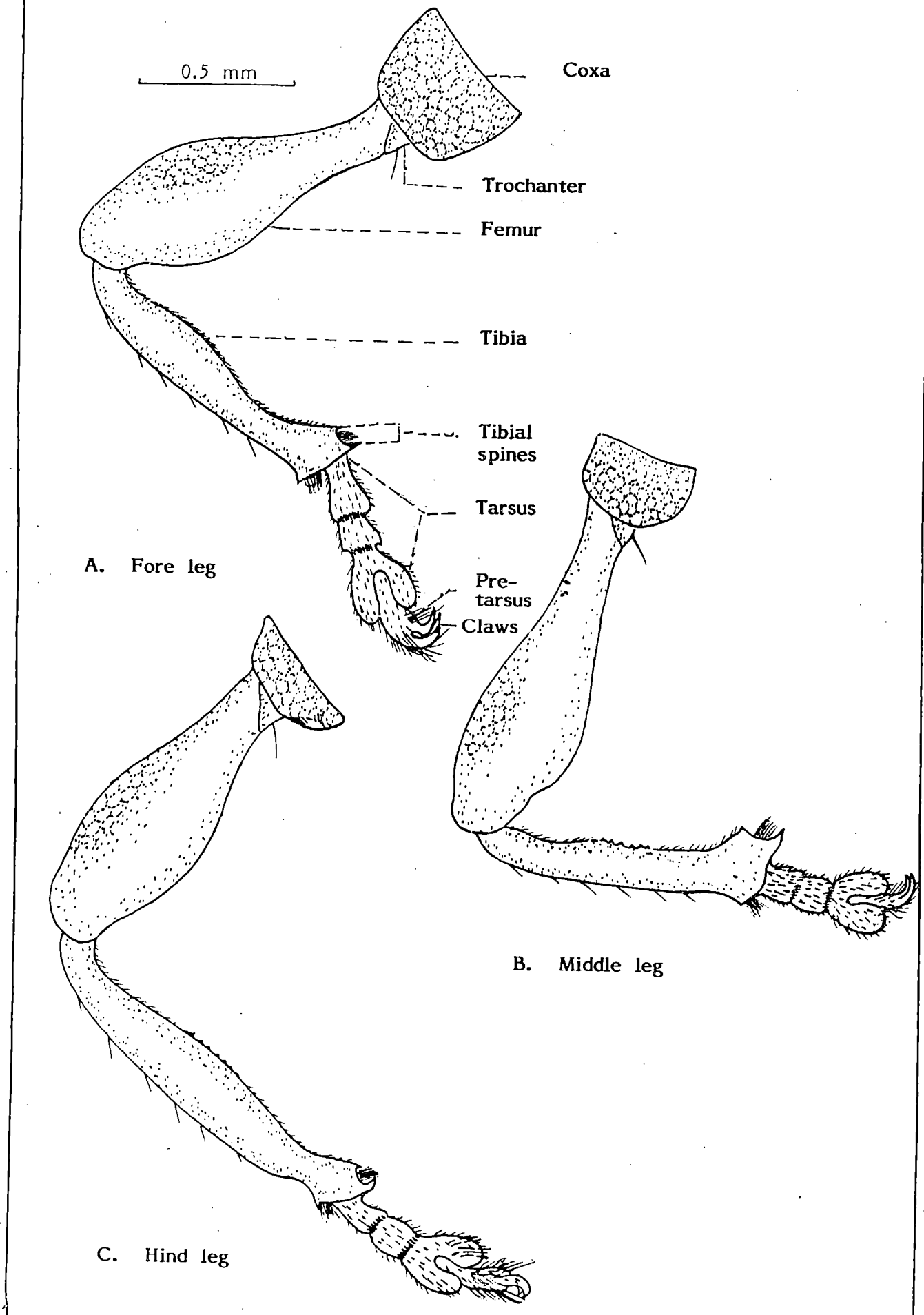


FIG. 9 Legs of female N. eichhorniae

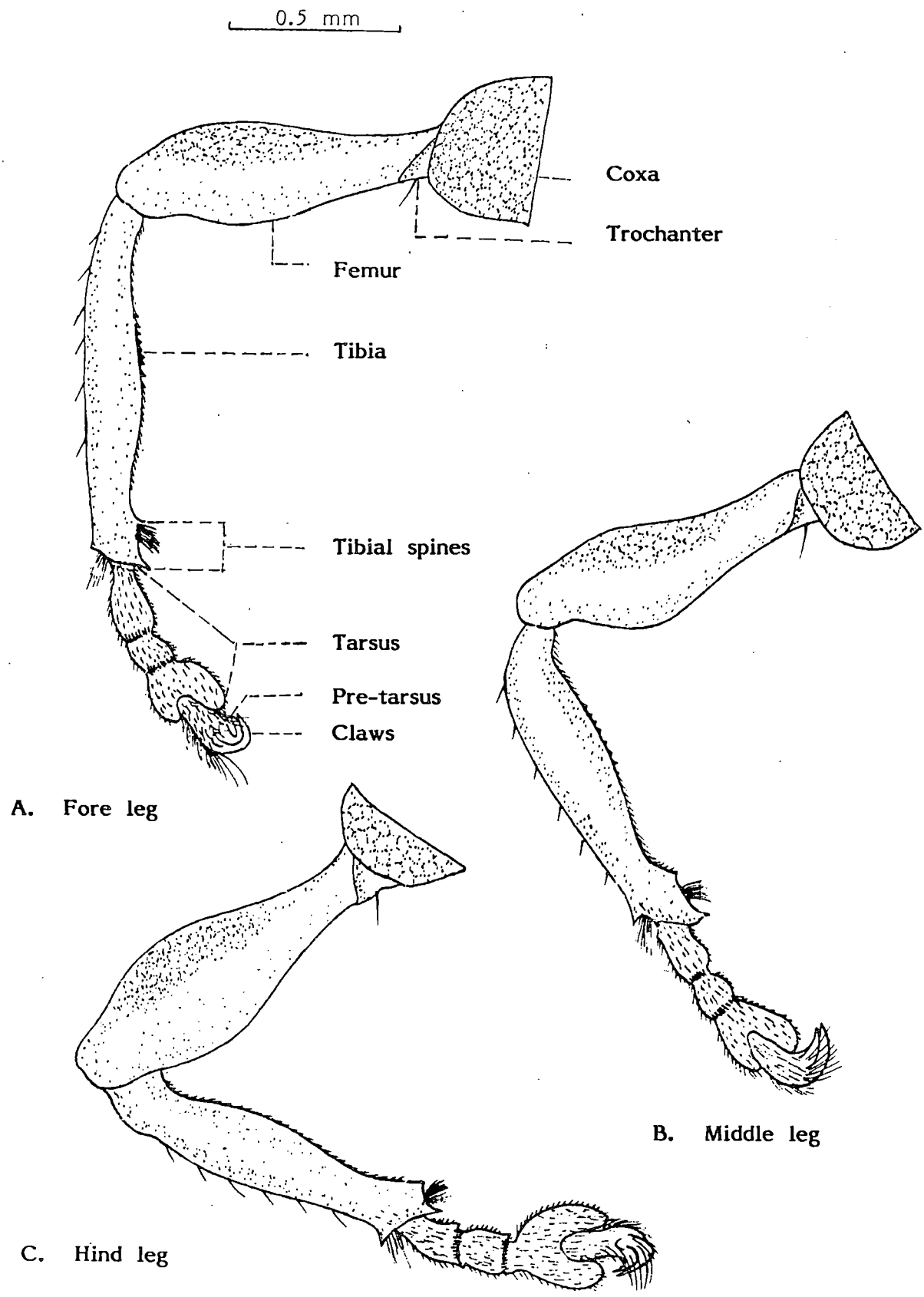


FIG. 8 Legs of male N. eichhorniae

margin had six small hair like processes. The long fine setae found on inner margin became denser and larger towards the apex. The inner margin had very fine tooth like projections on the mid portion. Apex of the tibia was expanded and possessed two prominent spurs on the innerside. The hind tibia was longer (1.38 mm) than the mid (1.24 mm) and fore (1.27 mm) tibia.

Tarsi were short and broad with three segments. The first segment was longer than the second, the third segment being strongly bilobed and much broader than the others.

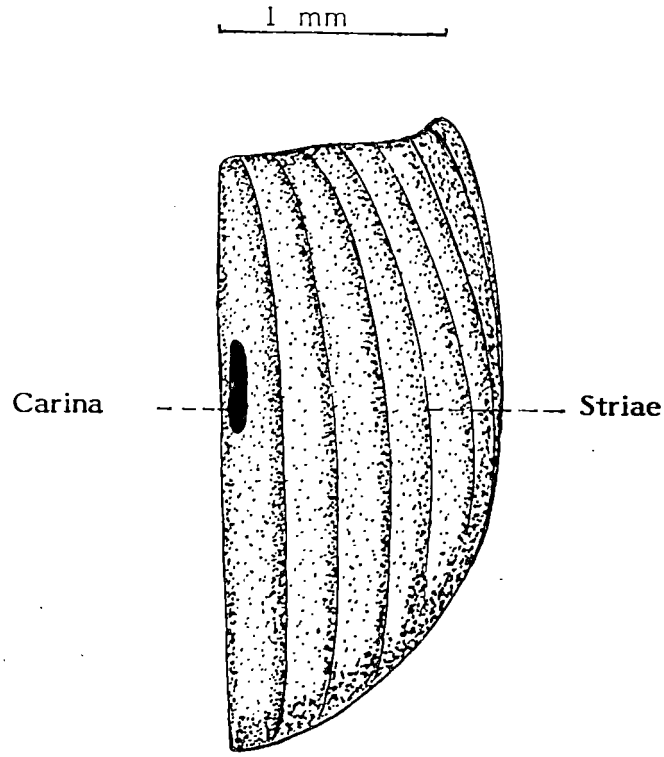
All segments were densely clothed with hydrofuge scales and with fine pubescence ventrally as well. Pre-tarsal segment extended well beyond third tarsal segment. It was covered with dense hydrofuge scales and was finely pubescent all over. Claws were free, thick, strongly curved and weakly divergent.

In female, the differences between the length of fore (4.01 mm) and mid (4.15 mm), mid and hind (4.44 mm) and fore and hind legs were significant (Fig.9).

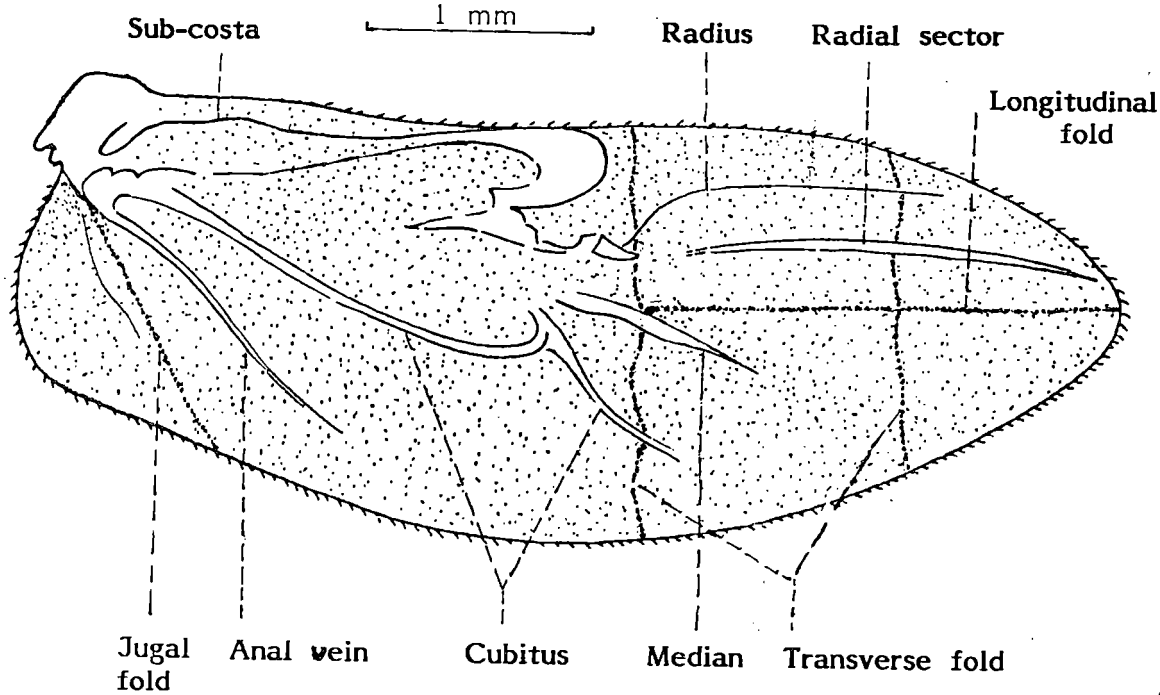
In male, differences in length of fore (3.64 mm) and mid (3.8 mm), mid and hind (3.98 mm) and fore and hind legs were significant (Fig.8) (Table 6).

4.2.6.7 Wings

The elytra were convex and chitinised and were wider than prothorax, being widest at the strongly angled humeri. The elytra were



A. Elytra



B. Hind wing

FIG. 10 Wings of N. eichhorniae

longer than wide (3.03:1.26 mm) and lacked tubercles. Carina on the elytra was long and located anteriorly. Striae were moderately coarse with punctures. The elytra was completely covered with dense scales (Fig.10A) and were held together by their tonguing and grooving and the mid dorsal line was distinct. The size of the elytra of the female (3.22 x 1.34 mm) varied significantly from that of the males (2.85 x 1.19 mm).

The hind wings were elongate, membraneous, and broad basally. Most of the veins were atrophied. The hind wing folded transversally as well as longitudinally, so that they could be accommodated beneath the elytra. This transverse fold necessitated a modification of the venation and there was a discontinuity between the proximal and distal parts of the veins. The distal end of the wing folded first longitudinally and twice transversely. The second transverse fold was at the middle region of the wing. Jugal fold was also present. Wing margins were armed with short hairs which were slightly longer at the posterior margin (Fig.10B).

Females had larger hind wings (7.07 x 2.06 mm) than the males (6.4 x 2.02 mm).

4.2.6.8 Abdomen

The abdomen was five segmented. In males, first segment was centrally depressed, the second being transversely flat and the fifth was with a broad median apical depression. The mean length of the abdomen was 1.5 mm.

In females, the first abdominal segment was with a deep and narrow transverse groove near the apex and the remainder was rather flattened along with second segment. The fifth segment was with a weak, broad median apical depression as in males. The length of the abdomen was 1.62 mm.

4.2.6.9 External genitalia

4.2.6.9.1 Male genitalia

The distal end of the aedeagus was prominently tongue shaped, arising from distinct shoulders, continued as long, slender aedeagal apodemes, one on either side. Apices of aedeagal apodemes were pointed. Aedeagus was with two elongate narrow, triangular sclerotised patches towards its caudal end and with a more or less round tip (Fig.11C). Flagellum was shorter or equal in length to phallus including apodemes.

Tegmen was having a cylindrical and a broadened part. The apical region was conical, broadly 'U' shaped and sclerotised. Lateral arms of tegmen were slender, sclerotised and united into a long median cylinder like process (Fig.11B).

The spiculum gastrale was having a narrow and a broad part. The base of the broad end was having a sclerotised plate like area. The two lateral arms joined together to form the narrow heavily sclerotised region (Fig.11A).

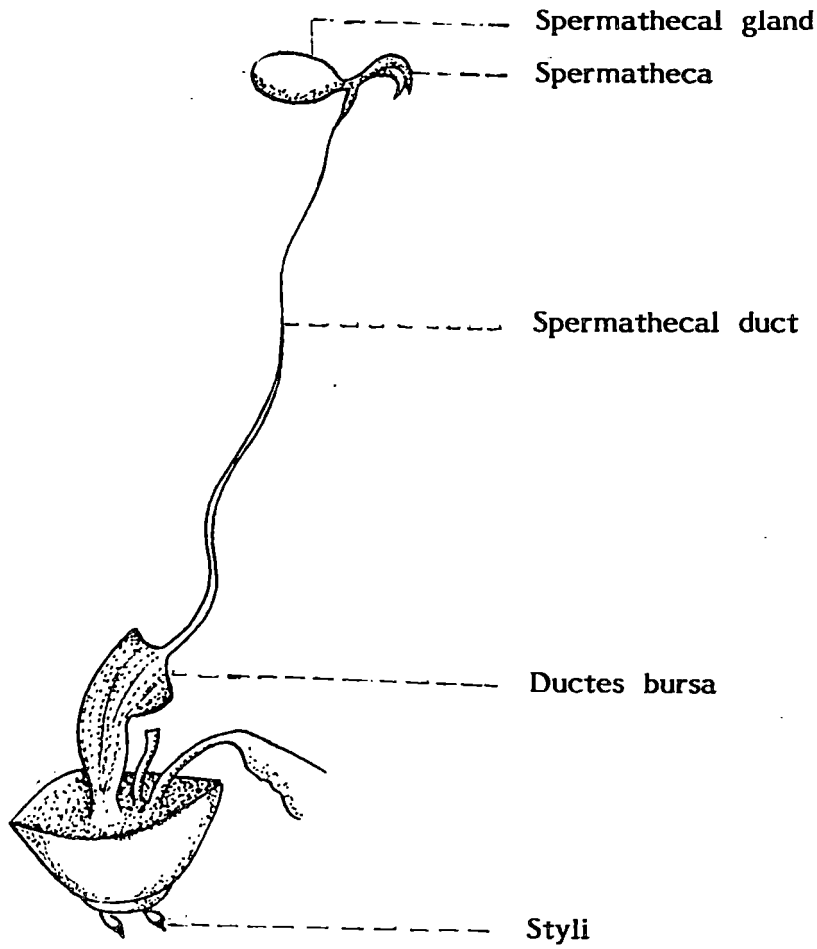
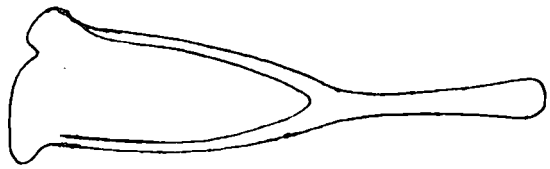
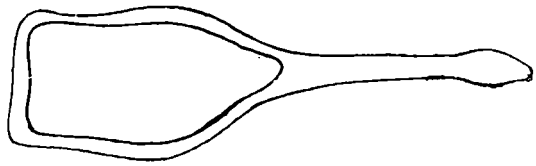


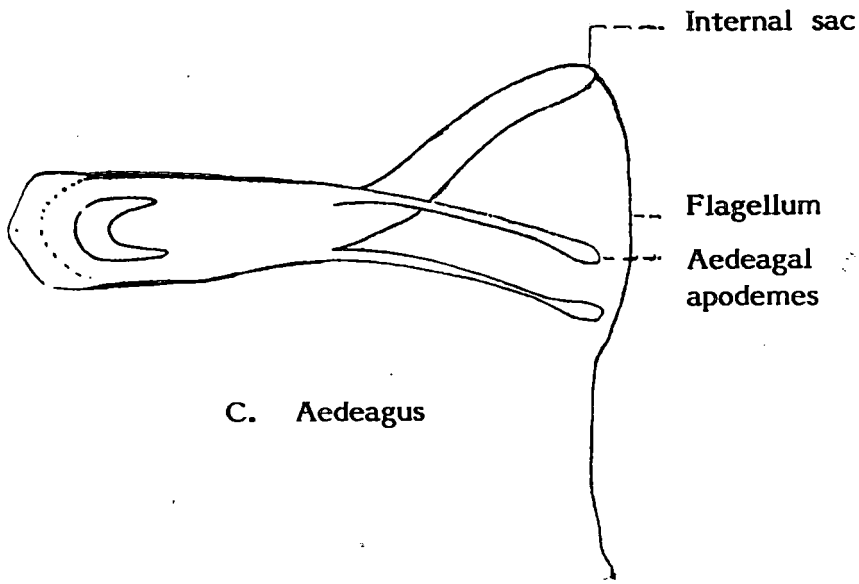
FIG. 12 Female genitalia of N. eichhorniae



A. Spiculum gastrale



B. Tegmen



C. Aedeagus

FIG. 11 Male genitalia of N. eichhorniae

4.2.6.9.2 Female genitalia

Bursa compulatrix was medium sized, cylindrical, with a fine duct of spermatheca at its cephalic region. Spermatheca was sclerotised, hard, hook-shaped and sac like spermathecal gland was attached to it. The bursa opened by a very short ductus to outside. A pair of short slender and blunt styli were also present (Fig.12).

4.3 Presence of natural enemies

The samples of natural population of N. eichhorniae collected from water hyacinth showed no microbes or mites as natural enemies.

The insects predating on the larvae and eggs of N. eichhorniae were the common non-specific predators. They included Dytiscid beetle (F. Dytiscidae), naiads of Dragon flies (O. Odonata), giant water bug (F. Belostomatidae: O. Hemiptera) and the back swimmers (F. Notonectidae: O. Hemiptera). The larvae of all the instars were consumed by these. But feeding on eggs was negligible. No predator was found feeding on adults.

4.4 Dispersal studies

The experiment conducted in plastic pools showed that the rate of dispersal of adults was very slow, being about 4-7 cm per day (average 5.31 cm). The dispersal was found to be random and non directional (Fig.13). Out of the 30 marked insects released, only 20 insects could be located after 24 hrs. On an average, four insects

Table 7 Mean rate of dispersal (cm) of N. eichhorniae (distance from the centre)

Replication Time (hrs)	I	II	III	Mean
24	4	12	7.5	7.83
48	12.5	17	14.6	14.70
72	18	22.5	17.5	19.30
96	23.3	25.5	22.7	23.56
120	30	33	25	29.3

remained at the site of release itself. The maximum movement of adult weevils per day was 15 cm. It was found that after 48 hrs, all the insects dispersed away from the released site. After 120 hrs, only three insects could be located and after 144 hrs, the number came down to two insects at an average distance of 45 cm away from the released site. On the first day, the average distance travelled by the insect was 6.97 cm and on the fifth day, it was 5.74 cm. As the duration increased, the distance of the insect from the centre also increased steadily (Table 7). Light traps were found unsuccessful as a means of attracting the insect.

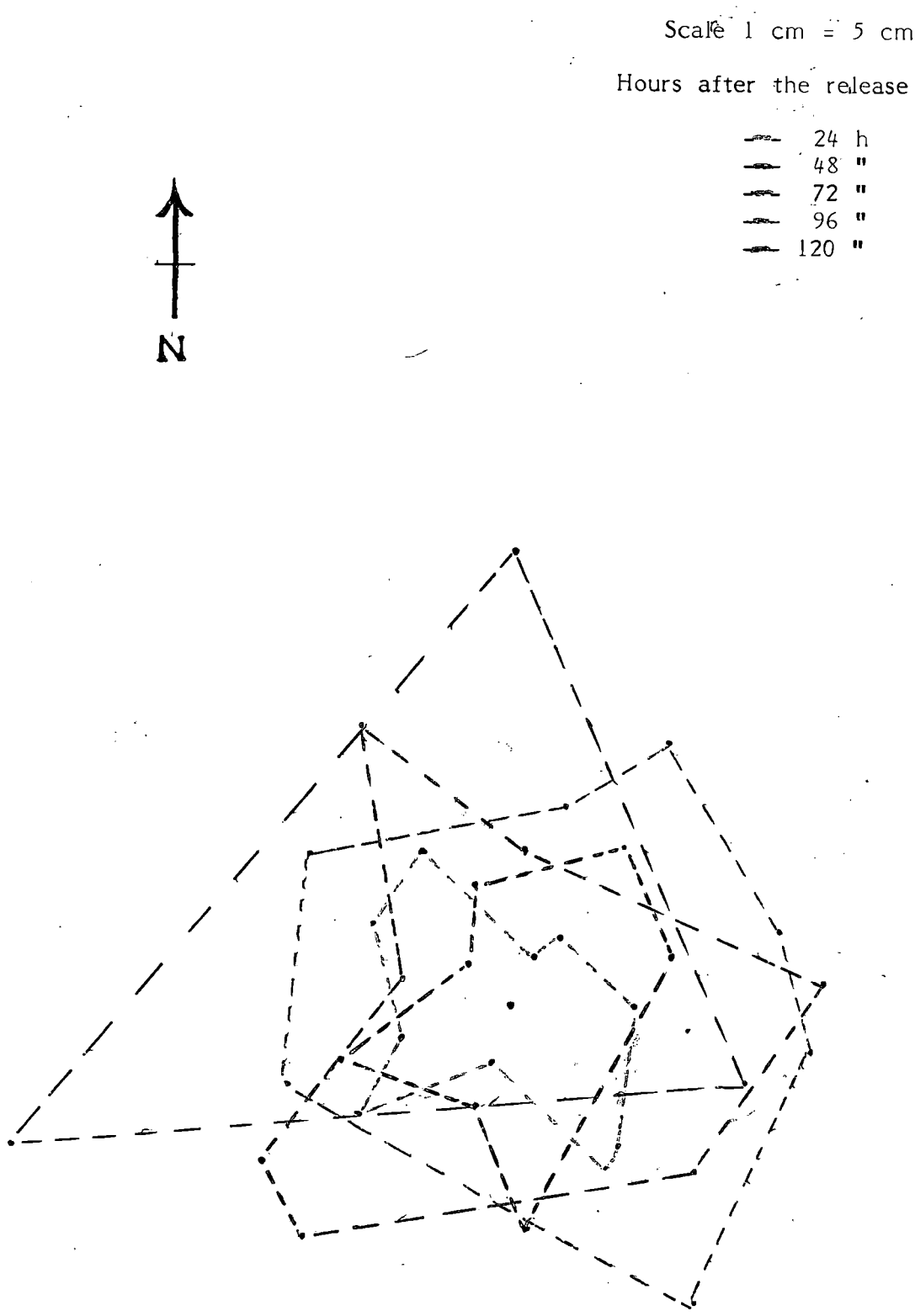


FIG. 13 Dispersal of N. eichhorniae

4.5 Nature of attack

4.5.1 Mode of attack of larvae

The first instar larvae burrowed under the epidermis of the leaf or upper petiole and tunnelled downward to the base of the leaf, feeding on the internal contents. The larvae were able to move from one petiole to another to obtain the required food. As the larvae grew larger, the galleries also became larger. The third instar larvae were generally located at the petiole bases and occasionally entered the stem (rhizome) and excavated small pockets at the point of attachment of the leaf. They also burrowed up the stem to enter the bases of young petioles and reached the stem apex and destroyed the apical bud. This type of damage was seen on plants where a large number of larvae were feeding. These larval tunnels and the surrounding aerenchyma collapsed resulting in the formation of sunken lines on the petiole. Many such blackened cavities were seen within the stem. The petiole thus dead, either got separated from the plant or became waterlogged and pulled the rest of the plant under water, resulting in death and disintegration of the plant.

4.5.2 Mode of attack of adult weevils

Feeding by the adult weevils is primarily on the lamina of the leaf. The insect preferred the youngest unopened leaves. The feeding damage caused was very distinctive and conspicuous. The feeding scars were either rectangular or round in shape, the length

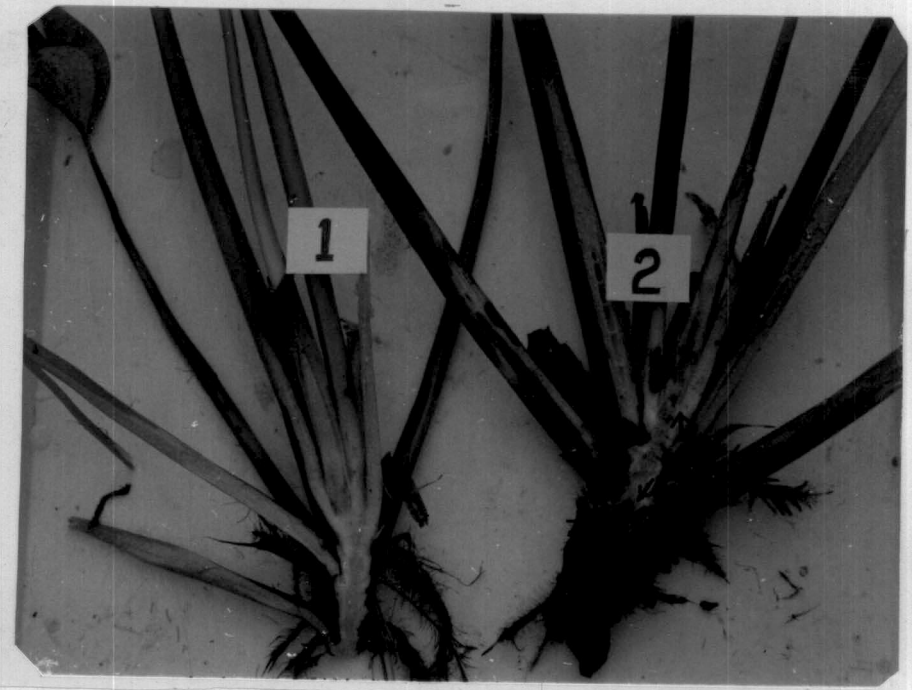


PLATE I Cross-section of healthy (1) and attacked (2) water hyacinth plants. Larval tunnels and rhizome rot is visible.

varied depending on the time spent by the weevil for feeding. The adults fed on the upper and lower sides of the lamina and also on the narrow upper one-third area of the petiole and often removed nearly all the epidermal layer from this area. These feeding spots did not penetrate completely through the pseudolamina unless the spot on one side lined up with a previous spot on the opposite side.

4.5.2.1 Size of the feeding scars

The scars made by the females were slightly larger than those made by the males. They ranged from small nicks on the leaf surface to large coalesced patches. Size of the feeding scars ranged from 0.41 - 45 sq mm, the average being 4.1 - 6.8 sq mm.

4.5.2.2 Feeding scars per unit area

The number of feeding scars varied with the weevil population per plant (Table 19). More scars were present on the anterior region of the upper lamina and to a lesser extent at the point of attachment of the petiole. Feeding scars per unit area ranged from 2-12, the average being 4-5 scars/cm^2.

4.5.2.3 Feeding preference by adults

Field samples showed that maximum number of feeding scars were on the upper lamina, while those found on the lower lamina and petiole were almost equal. Number of feeding scars on the upper lamina was significantly higher than that on the lower lamina and on the petiole.

Table 8 Feeding preference by the adult N. eichhorniae

Mean number of feeding scars on			CD
Upper lamina	Lower lamina	Petiole	(0.05)
173.48	40.75	37.25	60.53

4.5.2.4 Area damaged by adults

Average feeding by the female was 97.5 sq mm for 12 h period. The females fed 13 per cent more area during night than during day, but the differences was not significant (Table 9).

Table 9 Variation in feeding by the adults of N. eichhorniae during day and night

Mean leaf area fed by the weevils (sq mm) during		CD
	Day	Night	(0.05)
Male	29.22	36.27	NS
Female	91.55	103.60	NS

The males consumed 24 per cent more area during night than during day but the difference was not significant. Average feeding for 12 h period was 32.75 sq mm.

On an average the females fed 198 per cent more area than that fed by males and the values showed significant difference (Table 10).

Table 10 Comparison in the rate of feeding between the males and females of adult N. eichhorniae

Mean leaf area fed by the adult weevils (sq mm)		CD (0.05)
Male	Female	
32.74	97.57	36.02

The differences in the rate of feeding by the adult pairs during day and night was significant. There was 61 per cent more feeding during night than day (Table 11).

Table 11 Rate of feeding by the adult pairs of N. eichhorniae during day and night

Mean leaf area fed by the adult weevils (sq mm)		CD (0.05)
Day	Night	
153.1	246.5	43.92

4.6 Extent of damage caused by N. eichhorniae

The extent of damage caused by different loads of the weevils was ascertained by the manifestation of the reduction in size of roots, petioles, lamina, fresh weight, number of plants, and the number of leaves on the attacked plants.

4.6.1 Reduction in root length

The mean root length of both floating and rooting water hyacinth recorded is presented in Table 12. The analysis indicated a significant difference between treatments from 15th day onwards. The maximum root length recorded was in the free floating plants in the control tanks (76.3 cm) on 60th day and minimum in rooting type of growth with four weevils per plant. In control tanks, there was fourfold increase in root length, within 45 days. Plants with four and six weevils per plant initially showed an increase in root length and then a reduction. In the treatments with 8, 10, and 12 weevils per plant in both growth conditions all the plants were collapsed within a period of 30 days. This led to discontinuance of further observations. Plants in the rooting type also showed an increase in root length, but the rate was negligible. Eventhough the plants in tanks having four weevils per plant survived upto 55th day there was significant difference in root length compared to control. The root length of plants in that treatment also had reduced drastically by 45th day.

Table 12 Mean root length of E. crassipes, under two growing conditions at different population loads of N. eichhorniae as observed at different intervals after release

No. of weevils per plant	Length of roots of E. crassipes (cm) at different intervals (days) after the release of weevils				
	0	15	30	45	60
Floating plants					
0	17.48	38.48	47.8	71.33	76.3
4	19.3	29.46	22.6	a	a
6	19.86	28.4	22.5	a	a
8	18.39	25	a	a	a
10	17.14	26.76	a	a	a
12	18.96	24.85	a	a	a
C.D. for comparison (P=0.05)	NS	4.88 5.45+	6.4 7.01@		
Rooting plants					
0	19.23	27.4	28	29.5	31.0
4	19.86	20.33	18.33	9.44	a
6	16.34	16.34	a	a	a
8	21.23	20.56	a	a	a
10	19.36	21.6	a	a	a
12	21.74	27.63	a	a	a
CD for comparison (P = 0.05)	NS	4.88	5.72	5.68	

a = Completely collapsed

\+ = C.D. for comparison between 24.85 and other values

@ = C.D. for comparison between 22.6 and 22.5

4.6.2 Reduction in petiole length

The mean petiole length of floating and rooting water hyacinth recorded in the experiment is presented in Table 13. The analysis indicated significant difference between treatments from the 15th day onwards. The maximum petiole length recorded was in free floating control tanks (6.47 cm) on 60th day and minimum in rooting type of growth with four weevils per plant on 45th day, after the release of the weevils.

The petiole length of plants in control tanks of both types of growth showed an increase in the first fortnight, followed by a reduction and then again an increase. In all the other treatments, the petiole length recorded a decreasing trend. As the weevil load increased from zero to twelve, the petiole length recorded a decreasing trend with some exceptions, which is clear from the observations recorded on 15th day. In the treatments with 8, 10, and 12 weevils per plant in both the growth conditions all the plants collapsed within a period of 30 days which led to the discontinuance of further observations.

4.6.3 Reduction in laminar length

The mean laminar length of the floating and rooting water hyacinth recorded in the experiment is presented in Table 14.

The analysis indicated a significant difference between treatments from 15th day onwards. The maximum laminar length recorded

Table 13 Mean petiole length of E. crassipes under two growing condition at different population loads of N. eichhorniae as observed at biweekly intervals after release

Number of weevils per plant	Length of petioles of E. crassipes (cm) at different intervals (days) after the release of weevils				
	0	15	30	45	60
Floating plants					
0	5.62	5.74	5.04	6.26	6.47
4	5.16	4.7	2.45	a	a
6	4.54	3.63	2.91	a	a
8	4.81	4.19	a	a	a
10	4.92	3.2	a	a	a
12	4.88	3.14	a	a	a
C.D. for comparison (P = 0.05)	NS	0.325 0.363+	0.392 0.429@		
Rooting plants					
0	5.38	5.36	4.93	5.46	5.63
4	4.68	4.13	2.64	2.32	a
6	4.78	3.96	a	a	a
8	4.72	3.5	a	a	a
10	4.04	2.91	a	a	a
12	5.38	3.91	a	a	a
C.D. for comparison (P = 0.05)	NS	0.325	0.35	0.72	

a = Completely collapsed

\+ = C.D. for comparison between 3.14 and other values

@ = C.D. for comparison between 2.45 and 2.91

Table 14 Mean laminar length of E. crassipes under two situations at different population loads of N. eichhorniae as observed at biweekly intervals after release

Number of weevils per plant	Length of lamina of E. crassipes (cm) at different intervals (days) after the release of weevils				
	0	15	30	45	60
Floating plants					
0	3.66	3.84	3.48	4.26	4.41
4	3.43	3.16	2.66	a	a
6	3.46	3.04	2.43	a	a
8	3.3	2.91	a	a	a
10	3.46	2.62	a	a	a
12	3.29	2.95	a	a	a
C.D. for comparison (P = 0.05)	NS	0.435 0.486+	0.395 0.433@		
Rooting plants					
0	3.34	3.48	3.66	3.8	3.85
4	3.16	3.04	2.7	1.95	a
6	3.26	2.86	a	a	a
8	3.41	2.81	a	a	a
10	3.18	2.37	a	a	a
12	3.68	3.04	a	a	a
C.D. for comparison (P = 0.05)	NS	0.435	0.353	0.644	

a = Completely collapsed

\+ = C.D. for comparison between 2.95 and other values

@ = C.D. for comparison between 2.66 and 2.43

was in free floating plants in the control tanks on 60th day and minimum in treatment having four weevils per plant in rooting type of growth on 45th day. The laminar length of plants in the control tank of floating type of growth showed an increasing trend initially followed by a decrease and then again increasing trend, whereas the length in the control tank of rooting type of growth showed steady increasing trend. The laminar length of all the plants in all the treatments showed decreasing trend with time, in both types of growth condition. As the weevil load increased from zero to twelve, the length of lamina recorded a decreasing trend which is clear from the observations on 15th day after the release of the weevils.

4.6.4 Reduction in laminar width

The mean laminar width of the floating and rooting growth of water hyacinth recorded in the experiment is presented in Table 15.

The analysis indicated a significant difference between treatments from 15th day onwards. The maximum laminar width was recorded in control tank of rooting water hyacinth on 60th day and minimum in treatment having four weevils per plant in rooting growth on 45th day. The laminar length of plants in the control

Table 15 Mean laminar width of *E. crassipes* in association with different population loads of *N. eichhorniae* at different intervals after release

Number of weevils per plant	Width of lamina of *E. crassipes* (cm) at different intervals (days) after the release of weevils				
	0	15	30	45	60
Floating plants					
0	5.7	5.88	5.56	4.83	5.1
4	5.23	5.09	3.33	a	a
6	5.52	4.58	3.66	a	a
8	5.48	4.83	a	a	a
10	5.26	4.5	a	a	a
12	5.41	4.39	a	a	a
CD (P = 0.05)	NS	0.626 0.439+	0.523 0.573@		
Rooting plants					
0	5.05	5.5	5.76	5.83	5.97
4	5.11	5.14	3.68	3.03	a
6	5.14	4.88	a	a	a
8	5.36	4.56	a	a	a
10	4.73	4.0	a	a	a
12	5.93	4.97	a	a	a
CD (P = 0.05)	NS	0.626	0.468	1.01	

a = Completely collapsed

\+ = C.D. for comparison between 4.39 and other values

@ = C.D. for comparison between 3.66 and 3.33

tank of floating plants showed initially the tendency of increase, then a reduction and again an increase, whereas the data on laminar width in the rooting growth showed steady sign of increase. The laminar width in all the treatments showed decreasing trend. As the weevil load increased from zero to twelve, the laminar width showed decreasing tendency but with some exceptions, which is apparent from the data recorded on 15th day after the release of the weevils.

4.6.5 Reduction in fresh weight

The mean fresh weight of rooting and floating water hyacinth recorded during the experiment is presented in Table 16.

The analysis indicated a significant difference between treatments from 15th day onwards. The maximum weight (77.3 g) was recorded in free floating control tanks after 60th day and minimum (4.67 g) in rooting plants with four weevils per plant on the 45th day after the release of the weevils. The fresh weight of plants in the control tanks of both type of growth showed increasing trend. The fresh weight showed five fold increase (15.06 g to 77.3 g) in floating type of growth and four fold increase in rooting type of growth (13.26 g to 56.6 g). As the weevil load increased from zero to twelve, the fresh weight of the floating plants recorded on 15th day showed no tendency, but rooting plants recorded a decreasing trend, but with some exception.

Table 16 Mean fresh weight of E. crassipes under two growing conditions at different population loads of N. eichhorniae as observed at different intervals after release

Number of weevils per plant	Fresh weight of E. crassipes (g) at different intervals (days) after the release of weevils				
	0	15	30	45	60
Floating plants					
0	15.06	45.6	46.8	67	77.3
4	14.53	43.0	30.9	a	a
6	14.6	45.0	27.4	a	a
8	13.16	39.0	a	a	a
10	12.73	44.9	a	a	a
12	16.6	36.4	a	a	a
C.D. (0.05)	NS	9.86 11.02+	3.615 3.69@		
Rooting plants					
0	13.26	45.06	48.7	53.0	56.6
4	12.0	38.33	26.26	4.67	a
6	13.3	38.26	a	a	a
8	13.53	35.8	a	a	a
10	12.4	26.03	a	a	a
12	19.2	39.46	a	a	a
C.D. (0.05)	NS	9.86	3.23	11.66	

a = Completely collapsed

\+ = C.D. for comparison between 36.4 and other values

@ = C.D. for comparison between 27.4 and 30.9

4.6.6 Reduction in number of plants

The mean number of plants of the floating and rooting water hyacinth recorded in the experiment is presented in Table 17.

In the experiment, five plants each were used in all the treatments. In the treatment with 8, 10 and 12 weevil loads per plant, all the plants collapsed and sank into the tank by the 30th day and hence the analysis was carried out using $\sqrt{X}$ transformation. The analysis indicated no significant difference between treatments upto 30th day. The difference in number of plants was significant on 45th day in rooting type of growth between the control tank and the treatment with minimum weevil load. The number of plants showed a steady increase in the control tanks of floating type (5 to 27.3) and rooting type (5 to 37 Nos.). But the rate of multiplication retarded with time. On 15th day the number of plants in treatment tanks was nearly equal to that in control tanks.

4.6.7 Reduction in number of leaves

The mean number of leaves of the floating and rooting water hyacinth recorded in the experiment is presented in Table 18.

Here also $\sqrt{X}$ transformation of data was used to carry out the analysis. The analysis indicated a significant difference between treatments from 15th day onwards. The difference in number of leaves was significant between the control and the treatments from 15th day

Table 17 Mean number of plants of rooting and floating E. crassipes in association with different population loads of N. eichhorniae at fortnightly intervals after release

Number of weevils per plant	Number of plants of E. crassipes at different intervals (days) after the release of weevils									
	0		15		30		45		60	
Floating plants										
0	5	11.3	(3.36)	20.04	(4.47)		25.27		27.3	
4	5	9.31	(3.05)	4.19	(2.04)		a		a	
6	5	14.8	(3.84)	7.99	(2.82)		a		a	
8	5	15.33	(3.91)	a			a		a	
10	5	20.41	(4.51)	a			a		a	
12	5	10.22	(3.19)	a			a		a	
C.D. (0.05)	NS		NS		NS					
Rooting plants										
0	5	19.11	(4.37)	29.32	(5.41)		33.66	(5.8)	36.0	
4	5	17.41	(4.17)	20.31	(4.5)		10.27	(3.2)	a	
6	5	14.42	(3.79)	a			a		a	
8	5	16.23	(4.02)	a			a		a	
10	5	17.75	(4.21)	a			a		a	
12	5	15.54	(3.94)	a			a		a	
C.D. (0.05)	NS		NS		NS		1.43			

$\sqrt{X}$ transformation of data was made before analysis

The values given in parenthesis are the transformed data

a = Completely collapsed

NS = Not significant

Table 18 Mean number of leaves of E. crassipes in association with different population loads of N. eichhorniae at different intervals after release

Number of weevils per plant	Number of leaves per treatment of E. crassipes at different intervals (days) after the release of weevils								
	0		15		30		45		60
Floating plants									
0	28.32	(5.32)	76.87	(8.76)	122.1	(11)	121.59		128.4
4	24.99	(4.99)	50.7	(7.12)	27.44	(5.23)	a		a
6	26.3	(5.12)	65.42	(8.08)	53.83	(7.33)	a		a
8	24.6	(4.96)	55.57	(7.45)	a		a		a
10	24.99	(4.99)	72.0	(8.48)	a		a		a
12	25.99	(5.09)	102.9	(10.14)	a		a		a
C.D. (0.05)		NS		1.42 1.59+		2.76 3.03@			
Rooting plants									
0	27.64	(5.25)	128.3	(11.32)	171.8	(13.1)	117.99	(10.8)	126.3
4	24.32	(4.72)	74.74	(8.94)	99.03	(9.95)	67.3	(8.2)	a
6	23.99	(4.89)	70.48	(8.39)	a		a		a
8	24.59	(4.95)	80.21	(8.95)	a		a		a
10	23.99	(4.89)	74.56	(8.63)	a		a		a
12	27.59	(5.25)	63.6	(7.97)	a		a		a
C.D. (P = 0.05)		NS		1.426		2.47		10.22	

$\sqrt{X}$ transformation of data was made before analysis

a = Completely collapsed

NS = Not significant

\+ = C.D. for comparison between 10.14 and other values

@ = C.D. for comparison between 7.33 and 5.23

onwards, but the difference between treatments was not significant, with one exception, i.e. the comparison between the control and maximum weevil load in floating type of growth. On 30th day the difference between the control and treatments were significant in both type of growth condition. But on 45th day in rooting plants, the difference between the control and the treatment was not found significant. As the weevil load increased from zero to twelve, the rate of leaf production remained more or less constant.

4.7 Predicting the population intensity of adult N. eichhorniae from the incidence of feeding scars on leaves of water hyacinth

The data on population intensity and feeding marks are presented in Table 19. The data on the number of feeding marks on the second youngest leaf of the randomly selected plants and the number of weevils per plant were gathered (n = 58). The data were classified based on the number of weevils and the mean number of feeding scars per each weevil population was calculated. It was found that the most frequent weevil load was two (23 out of 58) followed by three (10 out of 58) and one (9 out of 58). No data were obtained from the samples involving the weevil population 5, 9 and 10. This grouped data was used for fitting the model. The model that best fitted for the data was the power function $I = aS^b$, Where I = mean number of adult weevils per plant, S = mean number of feeding scars per lamina, and 'a' and 'b' are constants. This was linearized by taking the logarithm to give $\log_{10} I = \log_{10} a + b \log_{10} S$.

Table 19 Details of samples drawn for studying the population intensity of *N. eichhorniae*

Weevil population	Frequency	No. of feeding scars per sample leaf	
		Range	Mean
1	9	96 - 385	210.1
2	23	106 - 383	242.3
3	10	202 - 358	271.5
4	5	208 - 416	312.0
5	3	310 - 348	333.0
6	-	-	-
7	2	396 - 507	451.5
8	4	324 - 601	440.5
9	-	-	-
10	-	-	-
11	2	403 - 536	469.5

Total n = 58

Correlation coefficient (R) 0.994^{a}

0.63^{b}

a = Worked out based on the mean number of feeding scars and the number of weevils.

b = Worked out based on the individual number of feeding scars and the weevils (unclassified data)

Constants:

$a = 6.1695 \times 10^{-8}$

$b = 2.72025$

So the relationship was $I = 6.1695 \times 10^{-8} \times S^{2.72025}$

Statistical analysis of the model revealed that there existed very high correlation (R = 0.994) between the observed and predicted values. The error of prediction was 1.19 per cent. The standard error of the estimate (S = 0.812) was very small, which indicated that the model was the best fit for the observed data.

Another model was prepared by taking the logarithmic values of the individual data on weevil population and the number of feeding scars (individual replications without computing the means) and a linear function was fitted by taking population as dependant variable.

The regression equation was $I = 0.0095\ S^{1.00896}$. The correlation coefficient (R) was 0.6301 and the error of prediction was 60.296 per cent.

PLATE II Control tank after 30 days (Floating growth)

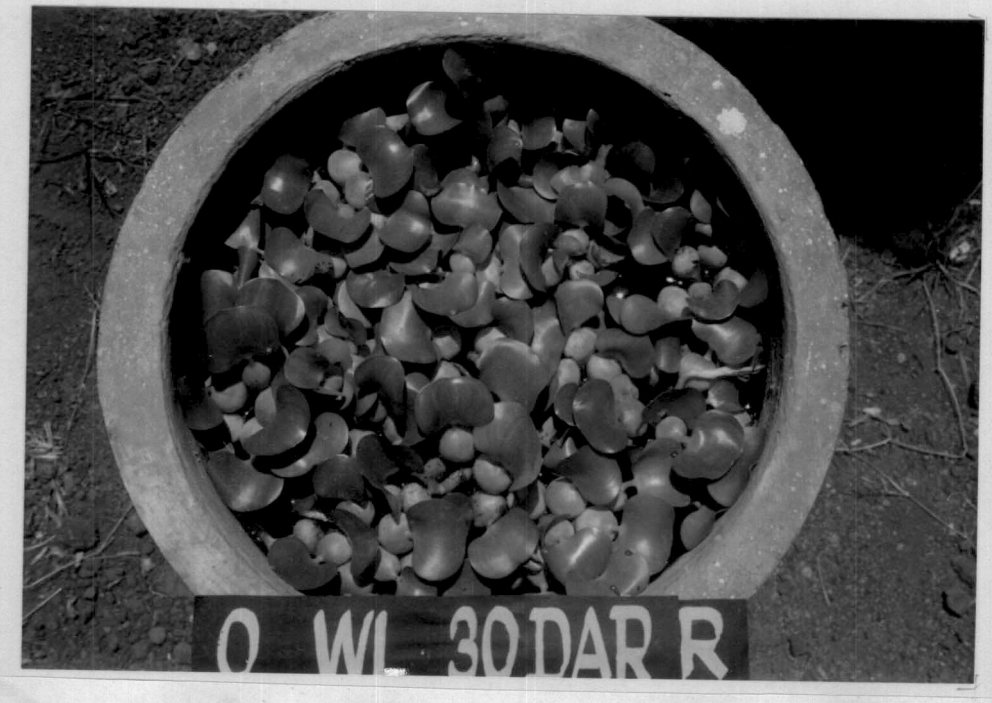


PLATE III Control tank after 30 days (Rooting growth)

PLATE IV Tank with four weevils/plant, 30 days after release (Floating growth)

PLATE V Tank with four weevils/plant, 30 days after release (Rooting growth)

PLATE VI Tank with eight weevils/plant, 30 days after release (Floating growth)

PLATE VII Tank with eight weevils/plant, 30 days after release (Rooting growth)

PLATE VIII Tank with twelve weevils/plant, 30 days after release (Floating growth)

PLATE IX Tank with twelve weevils/plant, 30 days after release (Rooting growth)

Discussion

DISCUSSION

The results of the studies on biology, morphology, nature of damage, dispersal, and population prediction of N. eichhorniae are discussed in this chapter.

5.1 Biology

The insect oviposited beneath the epidermis of leaves, petioles or ligules. The eggs were laid at the rate of one per hole and the insect preferred the lower leaf surface for egg laying. This observation is in conformity with the findings of Stark and Goyer, (1983). The incubation period ranged from six to nine days, the average being 6.6 days. The incubation period recorded by other workers were 7.6 days (Deloach and Cordo, 1976a) 7-14 days (Fosse, 1978b) and 8.1 days (Stark and Goyer, 1983). These variations are quite natural in view of the variation in the ambient temperature and humidity conditions. Deloach and Cordo (1976a) had reported that the incubation period was reduced with the increase in temperature.

The hatching percentage was 93.2 which was in line with the results obtained by Deloach and Cordo (1976a). Three instars were completed in about 8-10, 13-16 and 13-17 days respectively. Total larval period ranged from 34-44 days. This finding is in conformity with the observation of Stark and Goyer (1983) but contrary to that of Deloach and Cordo (1976a), who observed a larval period of 90 days.

The reason for the shorter larval period (34-44 days) obtained in this study could be attributed to the higher temperature (30.4°C) as compared to 25°C in which Deloach and Cordo conducted their studies.

The full grown larvae moved out of the tunnels and pupated just below the water surface. The cocoon was found attached to the roots The adults were not found to emerge when the pupae were detached from the roots at an early stage of development, while the emergence occurred from pupae, detached in an advanced stage of development. This is in agreement with the results of Deloach and Cordo (1976a) who suggested that there might be oxygen transfer between the plant tissues and the pupae. The pupal period ranged from 15-20 days. Fosse (1978b) had also observed pupal duration of the above range.

Life expectancy of adult female was 75.3 days (range 31-130 days) and that of the male was 172.3 days (range 129-232 days). This is in consonance with the observations of Fosse (1978b) and Jayanth (1987a) but at variance with the observations of Stark and Goyer (1983). They reported that the life expectancy averaged 57.8 $\pm$ 9.6 days. The variations in climatic conditions between the places where the biological studies were undertaken could be implicated to explain the moderate deviations in life expectancy data.

Pre-ovipositional period ranged from four to nine days and the ovipositional period prolonged till the death of the insect. The average number of eggs produced by a single female during the entire

period was 462.5 which is low compared with the number (891 eggs) obtained at Bangalore by Jayanth (1987a). This could possibly be due to the difference in climatic conditions between the places.

The female laid 100 per cent more eggs during night compared to that during day. Deloach and Cordo (1976a) had also observed the same phenomenon.

5.2 Morphology

5.2.1 Immature stages

The eggs were elongate, oval with an average size of 0.77 x 0.42 mm.

Freshly emerged larvae were creamy-white with yellowish-orange head as described in para 4.2.2 to 4.2.4. The present studies showed that the head capsule measurements of the larvae were similar to those reported by Deloach and Cordo (1976a).

As in majority of Curculionids, pupation took place in a cocoon, made out of plant parts and was attached to the living roots of the plants. The size of the pupal case averaged 6.4 mm. However, Stark and Goyer, (1983) recorded a slightly larger size of 6.9 $\pm$ 0.1 mm.

5.2.2 Adult

The males and females were of the same shape but the

females were larger than the males as explained in para 4.2.6. The measurements of size reported by Deloach (1975) are slightly bigger.

Detailed morphology of the adult is described in para 4.2.6 to 4.2.6.8.2. The antennal socket on the rostrum is found to be a key character by which the males and females of the insect could be easily distinguished. This helps in quicker identification of the sexes in field and for further studies in sex ratio, population build up etc. The morphological and biometrical observations were in line the observations of O'Brien (1976) and Deloach (1975). The slight variations observed were not significant.

5.3 Presence of natural enemies

The insect was infected with various microbes and mites in its native place, Argentina (Deloach and Cordo 1982). However, in this experiment, no mites or microbes were observed.

The predators observed were the common aquatic insects. They were not found to feed on the adult insect. They fed mainly on the third instar larva, especially when the larvae came out of the tunnels and move towards the upper root zone for pupation.

The non-specific natural enemies such as dragon fly naiads, dytiscid beetles, belostomatids, and the notonectid bugs were usually inhabiting the root zone of water hyacinth. Out of these, the damage caused by notonectid bugs was comparitively low, because of their

surface feeding nature, When the introduction of this new species was made, the common general aquatic predators in the aquatic ecosystem might have made changes in their host range to include the weevil grubs.

5.4 Dispersal studies

The experiment conducted in plastic pools revealed that the rate of dispersal of adults was very slow being about 4-7 cm per day. The dispersal was found to be random and non-directional.

Light traps were found ineffective as a means of attracting the insect. This is in conformity with the results obtained by Stark and Goyer (1983).

5.5 Nature of attack

The first instar larva burrowed under the epidermis of the leaf or upper petiole and tunnelled downward to the base of the leaf as described in para 4.5.1. The larval tunnels and the surrounding aerenchyma collapsed resulting in the formation of sunken lines on the petiole and blackened cavities in the stem. This was due to the secondary attack by various pathogens. The petiole thus dead, either got separated from the plant or became waterlogged and pulled the rest of the plant under water, resulting in death and disintegration of the plant.

The adult insect preferred the youngest unopened leaves. The feeding scars were either rectangular or round in shape. The

adults preferred the upper lamina to the lower lamina and petiole. These results are in conformity with the observations of Deloach and Cordo, (1976a) and Stark and Goyer, (1983). As a result of feeding, the photosynthetic area of the plant become reduced which made the plant vulnerable to attack by many pathogens.

On an average, the female damaged an area of 97.5 sq mm during the 12 h period, while in the case of males, it was 32.75 sq mm. Both males and females fed more during night, though the difference was not statistically significant. Stark and Goyer,(1983), however, reported that significant difference did exist between diurnal and nocturnal feeding. On an average, females fed 198% more leaf area than that fed by the males which was in agreement with the results of Deloach and Cordo, (1976a). The differences in the rate of feeding by the adult pairs (male and female) during day and night was significant.

5.6 Extent of damage

The extent of damage caused by the insect was ascertained on the basis of manifestation of different parameters. Analysis of the data indicated a significant difference between treatments from 15th day onwards except in the case of number of plants. This clearly showed that the effect of feeding by the adults and the larvae became conspicuous by this time. It was found that the plants in the tanks having 8, 10 and 12 weevils collapsed completely within 30 days in both the growing conditions of the plant (floating and rooting). From the

study on biology, it was computed that nearly 190 larvae would have developed within ten days, from four pairs of adults feeding of which might have resulted in complete collapse of these plants.

The plants in the tanks having 4 weevils per plant in floating type of growth collapsed within 45 days, whereas in rooting type of growth, collapse occurred only in 60 days. This showed that, plants in rooting type of growth showed greater tolerance to insect damage. This observation was in close agreement with the results of Forno (1981). For all the parameters, the minimum value recorded was in tanks with four weevils per plant in rooting type of growth. It may be due to the collapse of all mother plants and the parameters recorded were those of the daughter plants. In floating type of growth, plants in some replications in a few treatments completely collapsed. Hence the statistical analysis of the data was carried out using unequal replication method. Separate critical differences were computed for comparing these treatment means (vide Table 12).

The results indicated that there were significant difference in root length between treatments, recorded from 15th day onwards. Eventhough the plants in the tank having a load of four weevils/plant survived up to 55th day, there was a significant reduction in root-length as compared to those in the control. The rootlength of plants in that treatment was reduced drastically by 45th day.

As the weevil load increased from zero to twelve, the petiole length recorded a decreasing trend. This inverse relationship was also seen in the case of laminar length and laminar width.

Thus in the absence ofweevils(in control plots) the number of plants of both growing conditions (floating and rooting) showed a steady increasing trend, but the rate of multiplication decreased with time because of the limitations in space. The data relating to the number of plants and the number of leaves observed at 15th and 30th day in general did not show significant differences as compared to control (vide Table 17 and 18). This could be attributed to the fact that the attack of insect might have stimulated the plant to produce many daughter plants during the initial period.

The results of the experiment clearly showed that the smaller plants (fresh weight nearly 20 gm) could be killed within 45 days using four weevils (sex ratio 1:1) per plant under field conditions in floating type of growth and within 60 days under rooting type of growth. This is in conformity with the findings of Deloach and Cordo, (1976a) who reported that N. eichhorniae took 60 days for complete collapse of the plant under floating condition in the laboratry. Jayanth and Nagarkatti (1984) reported that, the insects took 13-16 weeks for causing complete collapse of the plants. But the plants used in that experiment were older,compared to the ones used in the present study. The average weight of the plants was nearly 450 g and this could be the reason for the longer time taken for the collapse. Under field conditions, the growth rate and vigour of the plants will be of high order because of the availability of unlimited space and nutrients. Thus, the weevil load required to bring about collapse will be high. The results emphasize the need to undertake a long term study using bigger plants and correlating the parameters. Even if cent per cent

control may not be achieved, the extent of stress caused by the insect on the plant can be calculated, as opined by Harris (1980).

The experiments on the integrated approach, involving the use of native and introduced phytopathogens such as Alternaria eichhorniae and Conospora rodmanii, the mite Orthogalumna terebrantis and various herbicides alongwith the weevil N. eichhorniae are to be undertaken.

5.7 Population prediction

Predicting the intensity of population of adult N. eichhorniae from the intensity of feeding marks on leaves of water hyacinth was attempted. Two models were found fit for the data. The first one was $I = 6.1695 \times 10^{-8} \times S^{2.72075}$ (where I = the number of weevils and S = the number of feeding scars). The correlation coefficient was found to be 0.994 and the standard error of the estimate was 0.812 and the error of prediction was 1.19 per cent. However, this model could not fully account for the high degree of variability in the observed data.

The most frequent number of weevils encountered under field condition was two. This could be attributed to the smaller size of the plant, though in certain plants the number was as high as 11. This could be due to the dispersal of the weevils to the healthy plants, from the collapsed plants which were present close to them. Under this situation, even with high weevil load, proportionately high feeding scars were not produced in limited time which resulted in high degree of variability in the observed data (Table 19). Thus, the

migration of weevils as reported by Haag (1986a) is confirmed. In prediction studies, sufficiently large samples should be drawn to compensate for the effect of migration.

In order to accommodate this variability in the observed data, another model was prepared by taking the logarithmic values of the individual figures on weevil population and the corresponding figures for the feeding scars. A linear function was fitted by taking population as a dependent variable.

The regression equation was $I = 0.00955^{1.00896}$. The correlation coefficient 'R' was 0.6301 and the error of prediction was 60.296 per cent. In this equation, the error of prediction was comparatively high. This model would be useful in predicting the field populations based on individual samplings.

Summary

SUMMARY

Experiments were conducted at the College of Horticulture, Vellanikkara during 1987-89 to study the biology, morphology and biometrics of N. eichhorniae Warner as well as the nature and extent of damage caused by the weevil on Eichhornia crassipes (Mart.) Solms. Studies on the estimation of field population and the dispersal pattern of the weevil were also undertaken.

The results of the study are summarised below.

Life cycle and biology

1. Eggs were laid beneath the epidermis of leaves, petioles or ligules, at the rate of one per hole. The mean incubation period was 6.6 days and the hatching percentage was 93.2.

2. The larvae tunnelled into the plant tissues. The first, second and third larval instars were completed in 8-10, 13-16 and 13-17 days, respectively.

3. The cocoon was made of the rootlets of water hyacinth and found attached to the living roots of the plant. The insect pupated just below the water surface. The pupal period, on an average was 16.6 days.

4. The adults congregated within the unfurled leaf of water hyacinth and scraped the epidermis. The adult females lived for a period of 75.3 days while the males lived for significantly longer period (172.3 days).

5. The insect mated periodically throughout the day and night. The average pre-ovipositional period was 4.9 days and the ovipositional period prolonged till the death of the insect.

6. The mean number of eggs produced by the females during the whole life-time was 462.5 and the mean egg production per day was 5.85.

Morphology and biometrics

1. Eggs were elongate, oval and creamy-white with a mean length and width of 0.77 and 0.42 mm, respectively.

2. Larvae were apodous. The width of the head capsule of first, second and third instar larvae were 0.3, 0.488 and 0.693 mm, respectively. Mandible length also showed significant variation between the instars.

3. The female insects were distinctly bigger than males. In males, the average distance between the antennal socket and the tip of the rostrum was 0.259 mm, whereas in females it was significantly longer (0.487 mm). This character helps in distinguishing the sexes.

Presence of natural enemies

No microbes or mites were found affecting the field population of the weevil. The predators found were the common, non-specific aquatic insects such as the dytiscid beetles, naiads of dragon flies, giant water bugs and the back swimmers.

Dispersal studies

The dispersal was found to be random and non-directional and the average rate of dispersal was only 5.31 cm per day. The insect was negatively phototropic.

Nature of attack

1. The first instar larvae burrowed under the epidermis of the leaf or upper petiole, tunnelled downwards to the base of the leaf. The second and third instars were found at the base of the petioles or crown. The dead petiole either got separated from the plant or became waterlogged and pulled the rest of the plant under water, resulting in death and disintegration of the plant.

2. The adult weevils primarily fed on the lamina of the youngest unopened leaves and also on the narrow upper one-third area of the petiole. The average size of the feeding scars was 4.1-6.8 sq mm. The number of feeding scars on the upper lamina (173.48) was significantly higher than that on the lower lamina (40.75) or the petiole (37.25).

3. The difference in feeding for the 12 h period between the female (97.5 sq mm) and the male (32.75 sq mm) was statistically significant. The males and females fed more during the night (36.27 and 103.6 sq mm respectively) than during the day (29.22 and 91.55 sq mm respectively).

Extent of damage

1. As the weevil load increased from zero to twelve per plant, the root length, petiole length and the length and width of lamina of plants in both growing conditions (floating and rooting), in general, showed a decreasing trend from 15th day onwards.

2. The parameters such as the number of plants, number of leaves and fresh weight in both growing conditions showed no such trend.

3. The plants in tanks having a load of 8, 10 and 12 weevils per plant completely collapsed within 30 days in both growing conditions.

4. The plants in tanks having four weevils per plant in floating type of growth collapsed within 45 days whereas in rooting type of growth, collapse occurred only at 60 days of the release of the weevils.

Estimation of field population

Prediction of the population intensity of adult N. eichhorniae from the incidence of feeding scars on the second youngest leaf of water hyacinth, was made. Two equations were developed. They were:

(1) $I = 6.1695 \times 10^{-8} \times S^{2.72075}$

(2) $I = 0.0095\ S^{1.00896}$

Where I = No. of weevils and S = No. of feeding scars.

The first equation would be useful, when average number of feeding scars in a sampling group is used, and the second equation would be useful when the number of feeding scars on an individual plant is used for the prediction of the number of weevils.

The results of the experiment stress the need to undertake a long term study using bigger plants, with emphasis on the parameters like root length, petiole length and fresh weight of plants. Thus, the extent of stress caused by the insect on the plant can be calculated even in case where 100 per cent collapse of the plant could not be achieved. The population dynamics of the weevils in relation to the different seasons of the year and in relation to different weather parameters deserve further studies.

The experiments on the integrated approach involving the use of native and introduced phytopathogens such as Alternaria eichhorniae and Conospora rodmanii, the mite Orthogalumna terebantis and various herbicides along with the weevil N. eichhorniae are needed.

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* Originals not seen

Appendices

Appendix - I

Analysis of variance table of the egg production of N. eichhorniae during day and night

Source	df	S.S.	M.S.S.	F
Treatment	1	2.112	2.112	2.226
Error	38	36.054	0.949	
Total	39	38.166		

Appendix - II

Summary of analysis of variance table of the larval head capsule width and mandible length of N. eichhorniae

Source	df	Mean square	
		Head capsule width	Mandible length
Treatment	2	0.239**	0.3176**
Error	15	0.001	0.000242
Total	17		

**Significant at 1 per cent level

Appendix - III

Summary of analysis of variance tables of the length and width of different organs of N. eichhorniae

Source	df	Mean squares					
		Adult			Rostrum		Antennal socket to tip of rostrum
		Length	Width	Antenna	Length	Width	
Treatment	1	1.0722 *	0.0945 *	0.124**	0.119**	0.002	0.130**
Error	8	0.01535	0.0176	0.005	0.006	0.001	0.003
Total	9						

Source	df	Mean squares				
					Elytra	
		Prothorax	Thorax	Abdomen	Length	Width
Treatment	1	0.011	0.041*	0.037*	0.371**	0.035*
Error	8	0.007	0.008	0.005	0.012	0.004
Total	9					

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix - IV

Summary of analysis of variance tables of the length of leg segments of N. eichhorniae

Source	df	Mean squares			
		Coxa	Femur	Tibia	Total length
Treatment	5	0.022**	0.064**	0.133**	0.394**
Error	24	0.001	0.002	0.002	0.009
Total	29				

** Significant at 1 per cent level

Appendix - V

Analysis of variance table of the preference in feeding by the adult N. eichhorniae

Source	df	S.S.	M.S.S	F
Treatment	2	60313.529	30156.764	15.629**
Error	12	23153.891	1929.491	
Total	14	83467.426		

** Significant at 1 per cent level

Appendix - VI

Summary of analysis of variance tables of the feeding studies with N. eichhorniae

Source	df	Mean squares			
		Feeding by adult males and females	Feeding by adult females during day and night	Feeding by adult males during day and night	Feeding by adult pairs during day and night
Treatment	1	21012.382**	726.016	248.512	43617.811**
Error	18	1469.666	5861.201	211.590	2185.298
Total	19				

** Significant at 1 per cent level

Appendix - VII

Summary of analysis of variance tables of the different growth parameters of water hyacinth plants observed at biweekly intervals after release of N. eichhorniae at different loads

Source	df	Root length	Petiole length	Laminar length	Laminar width	Fresh weight	Number of plants	Number of leaves
				Mean squares at 0 days interval				
Treatment	11	7.477	0.552	0.084	0.298	12.418	-	0.092
Error	24	5.483	0.428	0.062	0.129	3.825	-	0.033
Total	35							
				Mean squares at 15 days interval				
Treatment	11	96.313*	2.211**	0.427**	0.754**	93.645*	0.625	3.675**
Error	23	8.348	0.158	0.066	0.137	34.091	0.891	0.713
Total	34							
				Mean squares at 30 days interval				
Treatment	4	392.396*	4.422**	0.777*	3.583**	325.77**	5.674	24.210**
Error	8	9.258	0.184	0.187	0.062	15 678	1.939	1.727
Total	12							
				Mean squares at 45 days interval				
Treatment	2	2991.064**	13.059**	4.504**	6 055**	3216 474**	5 332**	1.006
Error	6	8.098	0.130	0.104	0.259	34.078	0.399	20.359
Total	8							

* Significant at 5 per cent level ** Significant at 1 per cent level

ABSTRACT

The biology, morphology, biometrics and dispersal pattern of the weevil Neochetina eichhorniae Warner and the nature and extent of damage caused by it on water hyacinth (Eichhornia crassipes (Mart.) were studied. An indirect method of estimating the field population was also attempted.

The insect laid the eggs beneath the epidermis of plant parts. Incubation period was 6.6 days and the hatching percentage was 93.2. The larvae fed by tunnelling, and the first, second and third larval instars were completed in 8-10, 13-16 and 13-17 days, respectively. The cocoon was attached to the live roots of the plant and the pupation was just below the water surface. The pupal period was 16.6 days. Adult female longevity was 75.3 days while that of the male was 172.3 days. Pre-ovipositional period was 49 days and the total number of eggs produced during the whole life period was 462.5.

The head capsule width of first, second and third instar larvae were 0.3, 0.488 and 0.693 mm respectively. In adult males, the average distance between the antennal socket and the tip of the rostrum was 0.259 mm and it was 0.487 mm in females. This character helps in the identification of sexes.

No microbes or mites were recorded as natural enemies. The predators were the common non-specific aquatic insects like dytiscid beetle, giant water bug, dragon fly naiads and back swimmers.

The adult dispersal was found to be at random and non-directional and the average rate was 5.31 cm per day. Light traps failed to attract the adults of both sexes.

The larvae tunnelled the petiole and crown of water hyacinth resulting in rotting and disintegration of the plant. Adult weevils made distinct feeding scars on upper lamina, lower lamina and the petiole.

As the weevil load increased from zero to twelve, the root length, petiole length, laminar length, laminar width, fresh weight, number of plants and number of leaves in both growing conditions (floating and rooting), in general showed a decreasing trend. The plants in tanks having four weevils per plant in floating type of growth collapsed within 45 days, whereas in rooting type of growth, the collapse occurred only at 60 days.

Prediction of the population intensity of adult N. eichhorniae from the incidence of feeding scars on second youngest leaf of water hyacinth was made. Two equations were developed. The equation $I = 6.1695 \times 10^{-8} \times S^{2.72075}$ can be made use of, for predicting the population (I) on the basis of average number of feeding scars (S) in a sample group. The equation $I = 0.0095 \times S^{1.00896}$ would be more useful when the number of feeding scars per lamina of an individual plant is employed to predict the population load per plant.