MANAGEMENT OF GIANT AFRICAN SNAIL *Achatina fulica* (BOWDICH)

by

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(2014-11-168)

THESIS

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695522

KERALA, INDIA

2016

DECLARATION

I, hereby declare that this thesis entitled **"MANAGEMENT OF GIANT AFRICAN SNAIL *Achatina fulica* (BOWDICH)"** 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, fellowship or other similar title, of any other University or Society.

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ACKNOWLEDGEMENT

I am pleased to place my esteem and deep sense of gratitude towards Dr. R. Narayana, Assistant Professor, Department of Nematology, College of Agriculture, Vellayani and honoured Chairman of my Advisory Committee for his scholarly suggestions, valuable advices and criticisms throughout my research work.

I am immensely grateful to my advisory committee members Dr. K. Sudharma, Professor and Head, Department of Agricultural Entomology, College of Agriculture, Vellayani, Dr. Nisha M.S, Assistant Professor, Departmentof Nematology, College of Agriculture, Vellayani, Dr. Sam T. Kurumthottical , Professor, Department of Soil Science and Agricultural Chemistry , College of Agriculture, Vellayani and Dr. Gavas Ragesh , Assistant Professor (Entomolgy) , Banana Research Station, Kannara ,since they have supported me with their valuable guidance, advice and inspiring encouragement throughout the course of work.

Special thanks to Dr. M.S. Sheela, Associate Director of Research and Head of the Department (Rtd.) Department of Entomology, and Dr. C. Gokulapalan, Professor and Head Department of plant pathology (Rtd.), College of Agriculture, Vellayani, since their valuable suggestions and constant encouragement supported me a lot to attain this goal. I am also thankful to Dr. C. Nandakumar, Dr. HebsyBai, retired Professors, Department of Agricultural Entomology, College of Agriculture, Vellayani and Dr. K. S. Prameela Associate Professor, Department of Agricultural Entomology, College of Agriculture, Vellayani for their valuable suggestions and support.

Gratitude is extended towards my teachers Dr. Jiji T, Dr. M.H. Faizal, Dr. K.D Prathapan, Dr. Ambily Paul, Dr. R. Krishnakumar, Dr. Reji Rani, Dr. Amritha, Dr. N Anitha, Dr. Thomas Biju Mathew and non-teaching staff of Department of Agricultural Entomology for their timely help, constant encouragement and co-operation given during the course work.

I am extending my sincere gratitude to Dr. R. Vijayan, Professor and Head, Dept. of Animal Husbandry (Rtd.), Dr. K. Umamaheswaran (ADR, NARP, SR), Dr. Elizabeth K. Syriac, Professor Agronomy, Dr. Mini C., & Dr. Geethalekshmi (Dept. of Processing technology), Dr. Jayalekshmi V. G. (PBGN), Dr. Sumam George (SSAC) and Brigith maam (Statistics) for their valuable support and suggestions

I gratefully acknowledge sunu chechi, Renjini, Sarath, Bipin, Vijayamuar chettan, Merlin chechi, Subhash, Sheba chechi, Sreelekshmy chechi, Santhosh ettan, Aswathy chechi, Jiji chechi, Chinjumol, Kishore ettan & Joseph (BRS, Kannara), Maneetha chechi (KFRI, Peechi) who helped me during my research work.

I would like to recall such moments and companionship of mine with my beloved ***Rare entoz****. Words are inadequate to express thanks to Jithumon, shiva, sunil, sherin, tamil, anusree, jasmy, pravi and aaruni.*

Words fail to express my sincere thanks to Shelvy, Eldhose, Sachin, Arya chechi, Sreejith ettan, Amala, kk, Achu ettan, Sachu chechi, Swetha, Vipin, Jacob, Rajesh, Akhil, Prasanth, Unnikuttan, Athul, Vishnu B. R., Rakhi, Vinod Alur, Lintu, other seniors, juniors and moreover my classmates of the P. G. family for their care, encouragement and companionship.

I wish to pledge my special thanks to my seniors, Murali chetan, Naveetha chechi, Nithya chechi, Darsana chechi, Akhila chechi, Aswathy chechi, Divya chechi, Amrutha chechi, Sangamesh chettan, Pritin Chettan, Anju chechi and to my juniors gayathri, lizz, ann, mithra, hari, varsha, Archana, chinchu and nimisha for their help and support.

Finally, I wish to register here my deepest and utmost gratitude to Achan, Amma, ettan and chechi for standing beside me throughout all the tumultuous times I have been through and for all the immense emotional strength they gave me to face all my fears and chase my dreams. I am truly indebted to them for all that I am today.

Mridul Vinod P.

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LIST OF ABBREVATIONSAND SYMBOLS USED

@	At the rate of
^{0}C	Degree Celsius
%	Per cent
µL	Micro litre
AFFA	Agriculture Fisheries and Forestry Australia
APFISN	Asia Pacific Forest Invasive Species Network
CD	Critical difference
CRD	Completely Randomised Design
cm	Centimetre
et al.	And others
EC	Emulsifiable Concentrate
EDTA	Ethelene Diamine Tetraacetic Acid
g	Gram
g L^{-1}	Gram Per litre
GAS	Giant African Snail
G	Granule
HAT	Hours After Treatment
i. e.	That is
IUCN	International Union for Conservation of Nature
ISSG	Invasive Species Specialist Group
IJ	Infective Juvenile

KAU	Kerala Agricultural University
Kg	Kilogram
Kg ha^{-1}	Kilogram per hectare
L	Litre
L^{-1}	Per litre
LC_{50}	Lethal Concentration
Mg	Milligram
mL^{-1}	Per millilitre
NSKE	Neem Seed Kernel Extract
Ppm	Parts per million
SD	Standard Deviation
SC	Solution Concentrate
SL	Soluble Liquid-
SP	Soluble Powder
viz.	Namely
WG	Wettable Granule

Introduction

1.INTRODUCTION

Alien species are non-native or exotic organisms that occur outside their natural adapted habitat and dispersal potential. Many alien species support our farming and forestry systems in a big way. However, some of the alien species become invasive when they are introduced deliberately or unintentionally outside their natural habitats into new areas where they express the capability to establish, invade and outcompete native species. (Raghubanshi *et al.*, 2005). Giant African snail (GAS), *Achatina fulica* Bowdich is one of the most notorious alien species that got established in India.

GAS is considered to be economically most important member of the family achatinidae. The branch of science which deals with phylum- Mollusca is called as malacology. Molluscs are second most in number and diversity after insects. Both terrestrial and aquatic individuals are included in this phylum. Snails are those organisms which comes under phylum mollusca with an external calcareous shell. Whereas, slugs are devoid of the external shell. Nowadays, phylum Mollusca has gained importance due to wide distribution of *A. fulica*. Mead (1961) stated that, "the story of economic malacology is invariably the same of GAS". As the name indicates, it is the biggest among gastropods and it was believed to be originated from East Africa. The presence of strong calcareous shell, generalist consumptive patterns, high reproductive rate, inadequate quarantine system and human interventions aided the rapid dispersal and establishment of this organism in various parts of the world (Fontinella *et al.*, 2007). According to the reports of APFISN (2011), GAS was reported from all continets except Antartica. Hence it was included in the list of hundred world's worst invaders.

The GAS is notorious for its polyphagous feeding habit. Mead (1961) enlisted a number of host plants of GAS. Now the list comprises of almost five hundred host plants (Capinera *et al.*, 2011) including both crops as well as non-crop plants. Attack of GAS is more prevalent in nursery beds. The GAS is not only found to create direct damage to crops but also indirect damages. It was reported to have role in disseminating the spores of *Phytophtora* sp. the causal organism of black pod rot of cocoa (Raut and

Barker, 2002). Moreover, it was acting as a vector for many plant and animal diseases. It was reported as a vector for the transmission of eosinophilic meningitis in human beings.

Different workers have suggested various opinions about its introduction to Kerala. However, nowadays it has become a serious pest of crops and non-crop plants grown throughout Kerala except high ranges. Moreover, it was found creating nuisance to public. Hence, these circumstances necessiates an emergency strategy to manage its exploding population.

One of the objectives of the present work was, to study the distribution of *A. fulica* and its natural enemies. Inorder to accomplish this objective, a survey was conducted in selected five hotspots belongs to various panchayats of Thiruvananthapuram district. During the survey, distribution of adults and juveniles of GAS and its natural enemies were studied. The host plants and the climatic conditions of the selected localities were also observed closely. Some other species of snails and slugs were also recorded as crop pests.

The other objective of the study was to develop effective management practices using plant extracts, chemicals and pathogenic nematodes. Chemical based management strategies were being adapted popularly for management of the snails. Metaldehyde is an important chemical widely used for the management of GAS. However, this chemical is having a broad spectrum effect and thus, adversely affect the environment by suppressing the non target native snail and slug fauna. Hence, alternative management strategies has to be developed for reducing the population of snails. For successful achievement of this objective, botanicals extracted from various plants and safer chemicals were evaluated against GAS at varying concentrations. The chemicals were applied both topically and as poison baits. Pathogenic nematodes and fungi were also evaluated for effective control of GAS. Various baiting and trapping techniques were also carried out as a part of the study.

Review of Literature

2. REVIEW OF LITERATURE

The giant African snail (GAS) was considered to be the most important crop pest among the phylum Mollusca (Mead, 1961). According to the experts of ISSG (2012), the GAS originated in East Africa (Kenya and Tanzania) and now they are distributed all over the world except in Antarctica. The *A. fulica* was identified as a native of East Africa. However, it was recorded from all continents except Antarctica and was reported to create a huge crop loss across the globe (Simberloff, 1995). Higher population of GAS was reported by Koyano *et al.* (1989) from Japan., Graeff-Teixeira *et al.* (1995) from India, Indian ocean islands, Australia and South-East Asia, Godan (1983) from American continent respectively. They are highly adaptive to a wide range of environmental conditions and are capable to modify its life cycle according to the local conditions. Moore (2005) reported that GAS consumes large volumes of native plants (polyphagous), modifies habitats and out-compete native snails. According to the APFISN pest fact sheet (2011), GAS was reported as a threat to the sustainability of crop systems and native ecosystems, creating a negative impact on native fauna, and a vector of human diseases.

2.1 SYSTEMATIC POSITION

A. fulica belongs to phylum Mollusca, which includes variety of organisms with diverging ecological niches. The taxonomic hierarchy of GAS is as follows, Class: Gastropoda, Sub-class: Heterobranchia, Order: Pulmonata, Infra Order: Stylommatophora, Family: Achatinidae, and Subfamily: Achatininae (Bequaert, 1950).

Gastropoda, previously known as univalves are a highly diversified class among the phylum Mollusca. It accounts for about 60,000 to 80,000 living snail and slug species. However, the anatomy, behavior, feeding, and reproductive adaptations of gastropods vary significantly from one group to another (Fryda *et al.*, 2005). The

class gastropoda includes a vast range of named species and stands second to the insects in overall number (Strong *et al.*, 2007).

The order Pulmonata, are characterized by the presence of a pallial lung instead of gills by which they can breathe. The group includes many land, freshwater and marine families. Most of the pulmonates were hermaphrodite in nature.

The family Achatinidae includes about 200 species under 13 genera. Most of which attained pest status in habitats modified for human habitation.

A. fulica has a narrow, conical shell, which is twice as long than its width and has 7 to 9 whorls when fully grown (Raut and Barker, 2002). Cooling (2005) reported that the average shell length of adult GAS varies from 5 to 10 cm and may exceed 20 cm and the average weight of an individual snail was 32 g. The shell is generally reddish-brown in colour with weak yellowish vertical markings but colouration varies with environmental conditions and diet (Mead, 1961; Raut and Barker, 2002).

2.2 INTRODUCTION TO INDIA

In India, GAS was introduced to Chouringhie gardens of Calcutta in 1847 by the British Conchologist William Henry Benson and from there it got dispersed to other parts of the country in course of time (Mead, 1961). According to him, by the year 1907, it became common in the gardens of Calcutta and by the year 1910, it got spread to Bombay. During 1946-47 it was reported from Bihar and known to cause crop losses (Srivastava, 1992). In Andaman and Nicobar Islands, it was reported to be introduced by the Japanese during the Second World War, indicating a second route of introduction of the pest into India (Srivastava, 1992).

2.3 PEST STATUS AND NATURE OF DAMAGE

A. fulica was reported to be a pest of various plants from different parts of the world, moreover it was known as a nuisance to public (Thakur, 1998).

2.3.1 Pest status and economic damage to crops

2.3.1.1 Pest status

Mead (1961) enlisted 86 plants which were preferred by GAS to varying degree. Raut and Ghose (1984) observed that nearly 90 per cent plants cultivated in India were susceptible to *A. fulica*. Raut and Barker (2002) reported 225 plant species which were fed by the GAS. Capinera (2011) identified that more than 500 plants were attacked by GAS.

According to Raut and Barker (2002) different crop plants were reported as hosts of GAS *viz.* bitter gourd (*Momordica charantia* Linn.), coffee (*Coffea* spp.) and various taro species (*Alocasia macrorrhizos* Donn., *Colocasia esculenta* Schott., *Xanthosoma brasiliense*). They found that apart from damaging the cultivated trees and shrubs such as cacao (*Theobroma cacao* Linn.), tobacco (*Nicotiana tabacum* Linn.), tea (*Camellia sinensis* Kuntze.), rubber (*Hevea brasiliensis* Mull.Arg.) and teak (*Tectona grandis* Linn.), they also attacked the weeds covering the ground and on the species of shade trees grown in between crop plants.

The susceptibility of plants attacked by GAS vary depending on the composition of the plant community in an area (Raut and Barker, 2002). They also suggested that the extent of damage by GAS to crops will vary between agricultural systems *i.e*, monoculture and crop species mixtures. Raut and Ghose (1984) observed that in the presence of many kinds of preferred food plants, *A. fulica* rarely attack *Canna indica* Linn., but often use this species for daytime shelter.

In contrast, *C. indica* was completely defoliated within a few days when the preferred host plants were no longer available (Manna and Raut, 1986).

Raut (1982) observed that out of 139 plants of okra, floral buds of 83 plants were damaged severely and no fruits were obtained from infested plants. Raut and Ghose (1984) enlisted 66 host plants from India and the extent of damage reported was from severe to negligible. Due to the menace of GAS in 24-pargana, Howrah, Midnapur and Calcutta of West Bengal and Balasore in Odisha, many cultivators had given up commercial cultivation of marigold since, there was an extensive damage by the snail (Thakur, 1998).

Olson (1973) reported GAS as an opportunistic, herbivorous and carpophagous organism. He found that 74.8 per cent of its food was scavenger type. Raut and Barker (2002) observed that at times the snails feed on sand, very small stones, bones from carcasses, even concrete as calcium sources for growth of its shell and in rare instances they will be cannibalistic.

2.3.1.2 Economic damage

The study conducted by Lelwala *et al.* (2010) revealed that, the mean crop loss caused by GAS during a cultivated season was to a tune of Rs. 57,922 ha^{-1} in Sri lanka. They also reported that the average income of a household per season after adopting necessary management interventions against GAS was Rs. 48,978 and that without adopting management interventions was, Rs. 41,448. This resulted in 18% increase in household income *i.e*, Rs. 7,530 per season.

A six-year campaign to eradicate the GAS from Florida concluded in 1975 at a cost of one million dollars (Simberloff, 1995). Economists estimated that, if the infestation of this pest in 1969 had remained undetected, annual losses would have reached 11 million dollars (Smith and Fowler, 2003).

2.3.2 Nature of damage

Singh and Roy (1979) during the study on feeding behaviour of snail, found that snails started feeding on the leaves from the margin inward and a feeble sound of eating was audible (Plate 1).

Irrespective of crop, the seedling or nursery stage was the most vulnerable stage of attack by the pest. In mature plants the nature of damage varies with the host, sometimes involving defoliation and in others involving damage to the stems, flowers or fruits (Raut and Barker 2002).

. According to Bhattacharya *et al.* (2014), the plant materials which were fed by the individual exhibit symptoms like extensive rasping (scraping), defoliation, slime trails and presence of ribbon like excrement.

The aggregated nature of the infestations by GAS can lead to severe damage in infested plants (Raut and Barker 2002). Schreurs (1963) reported that, snails having a shell length of 60 mm consumed food materials weighing 10 per cent of their body weight. The population density of GAS was recorded as 46 m^{-2} in mainland India and 56 m^{-2} in Andaman and Nicobar Islands (Raut and Barker, 2002). Muniappan *et al.* (1986) estimated that 45 million individuals of *A. fulica* were collected and destroyed from1600 hectares over a seven-month period. Muniappen (1987) reported population density of GAS to a tune of 73 $m^{-2}$from Maldives.

According to Mead (1979a); Schotman (1989), the activity of GAS was identified as one of the factors responsible for the dispersal of plant diseases. They reported about the key role of GAS in dispersing *Phytophthora palmivora* Butler on various crops such as black pepper, betel vine, coconut, papaya and vanilla. They also reported the dispersal of *Phytophthora colocasiae* Butlerin taro and *P. parasitica* in brinjal by the GAS. They observed that, the fungal spore got attached with the body of GAS easily and it got disseminated to other plants as a result of snail's activity.

a) Adults

b) juveniles

Plate 1. Feeding behavior of *A. fulica*

Watson (1985) reported *A. fulica* as an intermediate host of *Angiostrongylus cantonensis* Chen. from Queensland, Australia. Raut and Barker (2002) discussed the possible health threat by snails to human as carrier of *A. cantonensis*, the larvae of which was reported to cause eosinophilic meningitis in human beings.

The results of the investigations conducted by Jayasankar *et al.* (2010), revealed that GAS shells and meat solution served as breeding site for mosquitos, which were notorious for their role as a vector of various diseases to human beings. Hence, GAS was having epidemiological significance in mosquito mediated diseases.

2.4 BIOLOGY

Mead (1961; 1979) studied the biology and reproductive behavior of achatinidae. He explained the GAS as a nocturnal animal like other terrestrial gastropods. He also identified that they were active under high-humidity conditions and in many tropical areas, activity was thus restricted to the monsoon season and the following moist summer period. Raut and Barker (2002) reported that usually achatinids spend the daytime hours under protective cover and when populations are high, many *A. fulica* were found resting on exposed walls, tree trunks, indicating that under these conditions there may be a shortage of home sites. Activity generally commences with the approach of darkness at sunset.

For the activity of land snails, both humidity and temperature are necessary but, humidity plays a major role as is evident from the fact that even for hibernation/aestivation, they locate damp shady places, thick bushes and thick hedges etc. hence, they were unable to withstand dry weather and high temperature (Srivastava, 1992).

Takeda and Ozaki (1986) demonstrated an endogenous circadian rhythm in the activity of *A. fulica* that is independent of temperature and light conditions.

They also revealed that *A. fulica* became active when the ambient relative humidity rises above 50 percentage.

Panja (1995) found that foraging *A. fulica* spent an average of 338 min (55 per cent) for crawling, 95 min (15.5 per cent) for feeding and 180 min (29 per cent) for resting. He also identified that the distance travelled by *A. fulica* in a single night of activity decreased during the season irrespective of the age structure of the population, with an average of 1429 cm in June reducing to 912 cm in October.

Tomiyama (1992) found that, in Chichi Jima, Japan, immature *A. fulica* dispersed up to a distance of 100 cm (standard deviation 34 cm), while mature snails moved an average distance of 161 cm. Raut and Barker (2002) observed that, in the course of searching for food, *A. fulica* typically moves some distance from the daytime resting site before commencing feeding, the animals may be active for over an hour before locating a favourable host plant and foraging patterns were suspended when *A. fulica* is engaged in mating activity.

Mead (1949) recorded that the male sexual maturity in GAS commenced before it became a year old. Whereas, development of female organs and egg deposition takes a few months longer if, there is no prolonged interruption by aestivation or hibernation. Tomiyama (1991; 1993) demonstrated that *A. fulica* has determinate shell growth, with thickening of the shell peristome occurring after cessation of shell growth. However, during the shell growth phase the GAS also develop sexually, but producing only male gametes. In the later part of the male phase, the animals begin to engage in copulation. He also observed that at or shortly after cessation of shell growth, the individual completes its reproductive development and enter a phase where both male and female gametes were produced.

According to Lange (1950), mating is generally reciprocal. He also identified that pairing occurs between animals of similar size. Even though, the courtship may be initiated late in the afternoon, mating occurs during the hours of darkness.

Tomiyama (1994) found that, in *A. fulica*, courtship progressed successfully to copulation in only 10 per cent of observed courtships (Plate 2).

Lange (1950) reported the capacity of long-term storage of allosperm by the GAS. Hence, eggsmaybedepositedwithin8–20daysaftermating. Raut and Ghose (1979) observed egg production after 382 days of mating in *A. fulica*. Allosperm viability is evidently maintained over lengthy periods of aestivation (Raut and Ghose, 1982).

Mead (1949) reported retention of eggs in the sperm oviduct so that hatching occurs within a few hours of oviposition. Ghose (1963); Pawson and Chase (1984), reported that eggs with embryos in different stages of development were laid by GAS. Hence, the period of hatching varies, with some eggs hatching within a few days after laying. Mead (1949) found out that the eggs of Achatinidae were generally deposited in digs excavated in the soil by the gravid animal, but occasionally may simply be deposited in moist crevices among plant litter, stones and other debris on the ground.

Pawson and Chase (1984) observed that fecundity was maximal in *A. fulica* aged between 210 and 270 days under laboratory conditions. After that, the production of eggs declined markedly. Tomiyama and Miyashita (1992) demonstrated great variability in clutch size and egg size in *A. fulica*, with both parameters positively correlated with the size of the parent animals, clutch size varies from ten to four hundred.

According to Raut and Barker (2002), after emerging from the egg, achatinids generally remain underground with other members of the clutch for 4-7 days. During this time the hatchlings consume their eggshells, sometimes the eggshells of unhatched siblings and soil organic matter. After emergence from the soil, the young snails display exploratory and voracious feeding behaviour.

Plate 2. A pair of *A. fulica* engaged in copulation

Plummer (1975) reported an average longevity of 4.5 years for *A. fulica* kept in captivity in London, although specimens occasionally lived for 7.5–10 years. Whereas, under field conditions maximum longevity was usually 3–5 years (Mead, 1979; Tomiyama, 1993).

2.6 MANAGEMENT

Schotman (1989) reported that manual collection and destruction of the snails can be an effective control strategy when practised on a small scale or in organized campaigns involving the public or farmer groups.

Use of barriers against the movement and activity of snails have been practiced from years back and these barriers may simply be a strip of bare soil as a bund around the crop or may be a fence that comprises a screen of corrugated tin or wire mesh (Raut and Barker 2002). Bhattacharya *et al.* (2014) suggested that continuous lines of saw dust and ash can be used as barrier, but their effectiveness is drastically reduced once, they become wet. They also mentioned that lines of lime and copper sulphate which can be used as repellents to prevent the migration of pest in an area.

2.6.1 Use of attractant materials

In a study conducted by Thakur (1999) revealed that a bait mixture consisting of papaya pulp, extract of leaves of carpet legume and wheat flour as the most preferred bait of GAS. The experiment also revealed that, baits having papaya pulp attracted more number of GAS in comparison to other constituents. Mehendale and Bhagwat (2004) evaluated cabbage and cauliflower leaves for attracting land snail, *Ariophanta bajadera* as food lure traps. Ravikumara *et al.* (2007) showed that, more number of GAS were attracted to papaya stem and leaf waste followed by cabbage leaf waste. Fermented mixture of wheat flour and jaggery could also attract GAS (Ravikumara *et al.*, 2007). Vanitha *et al.* (2008) evaluated various attractants for trapping GAS. They used fermented neera, sugar + yeast combinations, beer and

cabbage leaves for the experiment. Among which yeast + sugar mixture was identified as the best in attracting the GAS followed by fermented neera. Shevale and Bedse (2009), evaluated the efficacy of different chemicals using attractant materials, based on fermented wheat flour. Mead (1961) suggested that, fortifying the leaf litter or other plant waste by molluscicide was an important methodology for trapping snails. Kalkanis *et al.* (2011) demonstrated a trap which can collect and kill the GAS using locally available low cost materials.

2.6.2 Natural enemies

GAS when introduced to a new area having favorable climatic condition will assume a pest status due to the lack of population regulation by pathogens, parasites and predators, at least in the early phases of invasion by the pest (Raut and Barker, 2002)

2.6.2.1 Pathogens

The leucoderma like disease caused a significant reduction in population of GAS from Sri Lanka during 1951-52 (Mead, 1961). He also found a significant reduction in population of GAS when solution prepared from dead snails were sprayed on healthy ones. Raut and Panirghani (1989) reported 8 different types of pathogen caused disease in GAS. Spraying an aqueous extract of diseased snails to food plants gave satisfactory control from the attack of *A. fulica* (Srivastava *et al.*, 1985).

Diverse associations of more than 108 described nematode species with slugs and snails provide a fertile ground for speculation of how mollusc parasitism evolved in nematodes. Wilson *et al.* (1995) isolated nine species of bacteria from the infective juveniles of *Phasmarhabditis hermaphrodita* Schnieder and the slugs infected by the nematodes. Wilson *et al.* (1995) selected *Moraxella osloensis* as a candidate bacterium to mass-produce *P. hermaphrodita.* Tan and Grewal (2001) found that *M. osloensis* produced a potent endotoxin that resulted in death of slugs.

Nematodes like *P.hermaphrodita, Steinernema longicaudatum* Nguyen & Smart,and *Heterorhabditis marelatus*were reported to kill 100 per cent slug population when applied @ 100 IJS/cm^2 (Kaya, 2001). *Steinernema* sp., *Heterorhabditis* sp. were found infecting slugs and snails (Jaworska, 1993). *Daubaylia potomaca, Pellioditis pelloides, P. hermaphrodita, P. papillosa, and P.neopapillosa* were able to multiply inside snail's body and cause infection and death (Grewal *et al*., 2003).

2.6.2.2 Predators

2.6.2.2.1 Invertebrates

The potential of *Platydemus manokwarii* DeBeachamp, as a predator of GAS was first discovered by Mead (1963) from Hawaii. Due to intense sucking by the predator, deep groves or holes were formed on the body of GAS. The *P.manokwari* emerged as a successful biological control agent, when introducedto Philippines (Muniappan *et al*., 1986). However, its introduction resulted in reduction in number of non-target organisms. *Bipalium indica* Graff., a flat worm was reported to attack on juveniles of GAS from India (Raut and Ghose, 1979a). They found that GAS was killed as a result of extra oral digestion by *B. indica*. They were not included in a successful biological control programme due to its reduced reproduction rate.

The predatory millipede, *Orthomorpha* sp. was found attacking on resting or inactive snails, by injecting a poisonous secretion to its body followed by scraping the body (Srivastava, 1992).

Among Mollusca, *Euglandina rosea* Ferrusac and *Gonaxis quadrilateralis* Preston. were found predating up on *A. fulica*. Mead (1979) reported about the classical biological control of GAS from Florida by the introduction of *E. rosea*. It was found as the most adaptable and abundant predator of GAS from Florida after its introduction. They were found feeding on the snails irrespective of their size. However, the broader feeding spectra of *E. rosea* lead to reduction in population of other mollusca. The sudden reduction of its population was also identified as another

drawback (Mead, 1979). According to Mead (1979) *G. quadrilateralis,* an efficient predator of GAS was introduced from Kenya to Hawaii and succeeded in reducing the population of GAS. However, it resulted in population decline of non-target snails.

Among arthropods, crustaceans and insects were found predating on GAS. The crustaceans include, hermit crab *Coenobita* spp. Mead (1950) reported the attack of hermit crab on mollusk from micronesia. He found that, the crabs pinched off small pieces of flesh with its chelae and killed the GAS. The predation of hermit crab on GAS from India was reported by Srivastava (1968) from the Islands of Andaman and Nicobar. He found that the release of hermit crabs on Andaman Islands helped in reducing the population of GAS. Schotman (1989), reported the low abundance of *A. fulica* in some Pacific atolls due to predation by hermit crabs *Coenobita perlatus* H. Milne-Edwards. Lake and O'Dowd (1991) showed that the omnivorous crab *Gecarcoidea natalis* provided biotic resistance to invasion by *A. fulica* in Christmas Island.

The insects of the order: coleoptera, diptera and hymenoptera were found predatory on molluscs. Among coleoptera, some insects of family – carabidae and lampyridae were found predating on snails. *Tefflus zanzibaricus alluaudi* Leach and *Tefflus purpureipennis wituensis* Leach were two important carbid beetles found predating on GAS (Mead, 1961). The Indian glow worm, *Lamprophorous tenebrosus* Walker was considered as a predator of GAS (Mead, 1961). Mead (1979) reported that the grubs of *L. tenebrosus* were feeding on the snails. However, the introduction of this predator was unsuccessful in reducing the population of GAS, due to its lower reproductive potential and reduced adaptability to various environmental conditions. The predatory potential of diptera were reported by a number of workers (Mead, 1979; Idris, 2001; Renato *et al.*, 2003). They found that, the maggots were saprophagous and feed on exposed fleshy parts of the body. Jayasankar *et al.* (2014) identified a number of entomofauna associated with GAS. Raut and Ghose (1984)

reported that, ants of the genus Oecophylla were carrying away the early juveniles of *A. fulica*. They reported three coleopterans, nine dipterans and six hymenopterans (including one belonged to family meliponidae) were predatory on snails.

2.6.2.2.2 Vertebrates

The Giant central American toad *Bufo marinus* Schneider was believed to be a predator of GAS since they reduced the population size of snails (Mead, 1961). Townes (1946) reported their distribution in japan. However, Lange (1950) proved that the Giant toad *B. marinus* was least successful as a biological control agent against GAS.

Raut and Ghose (1979b) found the bird treepie (*Dendrocitta vagabunda* Latham) and the crow pheasant (*Centropus siensis* Stephens) as natural enemies of *A. fulica*. However, they also reported that these birds predate up on the snails only during day time when the snails were found moving, after a shower or when the sky was overcast. Hence, these birds were not very effective as predators of GAS (Raut and Ghose, 1979b). The predatory potential of common duck was reported by Srivastava *et al*. (1970). They were found feeding on eggs and juveniles of *A. fulica* (up to 3 cm shell size). Khaki Campbell or Indian runner ducks are best breed to be used in snail control (Peter *et al*., 2012).

Among the mammals, the bandicoot rat, *Bandicota indica* Bechstein, was reported as a predator of GAS (Raut and Ghose, 1979b). They were able to locate the active as well as aestivating snails. According to Potts (1972) *Rattus rattus* Linn. was successful in reducing the population of *Cantareus asperses* Muller to a tune of 74 per cent. The predation potential of *R. rattus* on juveniles and adults of GAS was observed by Allen (2002). Landry (1970) reported that ground squirrels can feed on *A. fulica*. The local pig breed, *Sus andamanensis* Linn, was observed to be a voracious feeder of *A. fulica* and they were able to feed on an average of 3.80 kg

snails per day (Srivastava, 1992). Mead (1961) observed that, mongoose, *Herpestes mungo* lliger was an effective predator of GAS from Sri Lanka.

2.6.3 Botanicals

Botanicals like leaf extracts of tobacco, black pepper, neem were reported as toxic to GAS (Thakur, 1999). Jhansirani and Jaganmohan (1999) observed 53.81 and 91.14 per cent (cm^2) feeding inhibition of GAS after the application of neem seed kernel extract 4 % and neem oil 1 % respectively. Shoib *et al.* (2010) observed that application of nimbicidine @ 10 ml L^{-1} was effective in repelling the snail, *Monacha obstructa* Pfeiffer. They also observed that, a 100 per cent ovicidal action at the same concentration. Muley (1978) reported that 0.5% aqueous extract of neem seed was toxic against snail, *Melania scarbra*. Ayoub and Yankov (1985;1986) observed that aqueous extract of neem bark at 100 ppm concentration was effective against *Biomphalaria pefifferi* Preston. The leaf and bark extract of neem were toxic to the snail, *Lymnaea acuminata* Lamarck (Singh *et al.*, 1996). They also observed that, Nimbicidine was more toxic against *L. acuminata* than other neem based pesticides.

Jhansirani and Jaganmohan (1999) reported 79 per cent (cm^2) feeding inhibition of GAS after the application of *Annona squamosal* Linn. seed extract @ 4 %. The annonacin found in *Annona glabra* Linn. may be the compound responsible for the repellency against *A. fulica* (Dos *et al.*, 2001). Singh and Singh (2001) observed that the seed extract of *A. squamosa* was very effective in causing molluscicidal action. They also reported that, acetogenins extracted from *A. squamosa* was most toxic against snails than synthetic molluscicides. Combinations of equal parts of *A. squamosal* seed powder and oil from cedar or neem were able to produce a mortality higher than the individual components of these plants (Singh and Singh, 2001). Prasad *et al.* (2004) reported that the snails were repelled by the cuttings *of A. glabra*. To confirm the repellent and antifeedent activity of *A. glabra* against *A. fulica*, all the cuttings were planted closely as a fence around

Tagetes erecta Linn. nursery bed and they observed that *A. glabra* totally kept the nursery bed free from *A. fulica*, followed by *A. muricata*, *A. reticulata* and *A. squamosa*. Eventhough, these botanicals repelled the snails, there was no observation of mortality of snails due to *A. glabra.*

According to Rapado *et al.* (2013), *Piper crassinervium* Kunthand *Piper tuberculatum* Jacq. extracts at 20 mg L^{-1} and 30 mg L^{-1} respectively were able to cause 100 per cent mortality of snail, *Biomphalaria glabrate* Say.

Rao and Singh (2002) found *Cedrus deodara* Roxb. oil to be more toxic among molluscicides of plant origin against *A. fulica* in single treatments while in binary treatments a combination *of Cedrus deodara* + *Allium sativum* Linn. was found more toxic.

The molluscicidal effect of *Solanum* sp. was evaluated against *Biomphalaria alexandrina* Ehrenberg by Amer and Manal (2004). Plants like *Solanum paniculatum* Linn. (Solanaceae) contains chemical compounds such as saponins, tannins and glycoalkaloids, all of which have proven activity, against freshwater snails (Silva *et al.*, 2005).

Panigrahi and Raut, (1994) revealed the molluscicidal action of *Thevetia peruviana* Pers. A 100 per cent mortality of snails were reported after the application of *T. peruviana* kernel extract at 20 per cent concentration.

2.6.4 Chemicals

Application of pesticide (molluscicides) was considered as the most pragmatic approach for the control of terrestrial mollusc pests (Barker and Watts, 2002).

2.6.4.1 Inorganic chemicals

Singh and Birat (1969) reported the effectiveness of powdered common salt on the crawling *A. fulica*. Saxena and Dubey (1970) applied common salt in a higher

dose of 200 kg $ha^{-1}$for the management of snails. Raut and Ghose (1984) observed the application of common salt in killing GAS from Eastern India. The mortality of GAS due to the application of common salt was attributed to its dehydrating property (Shah, 1992). Karnatak *et al.* (1998) recorded hundred per cent mortality of GAS after 96 hours by the application of 5 per cent spray of sodium chloride. Prasad *et al.*, 2004 reported that by the application of common salt in a thickness of 12 inches around the infested areas can effectively manage the snails.

Saxena and Dubey (1970) reported 93 per cent mortality of GAS after the application of copper sulphate dust @ 5.5 kg ha^{-1}. Bharadwaj (1972) reported 95.80 per cent mortality of GAS after the application of copper sulphate and lime in the ratio, 40:60. Kakoty and Das (1988) recorded 100 per cent mortality using copper sulphate to manage the snails infesting tea estates. According to Kalyani (1990), copper sulphate can be utilized as effective molluscicide against *A. fulica*. She also reported that it can affect the total polysaccharide content of the snails. The digestive gland of molluscs was reported to be the major organ involved in accumulation and storage of metals. (Blasco and Puppo 1999; Snyman *et al.* 2005). The reproductive organs of molluscswere also known as targets of metal toxicity, affecting the structure and numbers of gametes (Snyman *et al.* 2004).

Barker and Watts, 2002 reported the mode of action of iron EDTA principally involves ferric ion interference with the oxygen uptake by haemocyanin, the respiratory pigment present in the haemolymph of molluscs. Ingestion of iron chelates killed the snails within 24 hours by arresting their food up take. However, they were not effective in causing paralysis of the molluscs. Chelates were found effective over metaldehyde and carbamate products since the level of mortality is independent of the water relations of the molluscs and thus not dependent on prevailing environmental moisture conditions (Clark *et al.* 1995).

2.6.4.2 Organic chemicals

Metaldehyde is the only registered molluscicide available in India. It was a derivative obtained from acetaldehyde (Henderson and Triebskorn, 2002). It was used as a molluscicide for the first time in South Africa during 1934 (Gimingham, 1940). According to Nair *et al.* (1968), the application of 1 % metaldehyde suspension resulted in 93.30 per cent mortality of GAS, whereas the application of metaldehyde 2 % dust formulation resulted in 100 per cent mortality of GAS. Srivastava *et al.* (1968), observed that the bait formulation including 5 % metaldehyde was able to cause mortality of GAS. Bharadwaj (1972) also reported that 5 % metaldehyde was more effective compared to other concentrations. According to Srivastava and Abbas (1973) the GAS was repulsive to metaldehyde dust. The mucous secreting cells of the snail were the target site of metaldehyde and adversely affect the water balance physiology of the molluscs thus resulting in their desiccation (Triebskorn and Ebert 1989). Metaldehyde has a secondary neurotoxic effect, contributing to loss of motor activity (Colosoet *al.* 1998). This molluscicidal activity was effected both through ingestion and dermal contact (Godan 1983).

Manna (1991) reported that acetylcholinesterase activity in the central nervous system and digestive gland of *A. fulica* was inhibited in a dose-dependent manner by diazinon and fenitrothion. According to his observations, 2 % and 1 % diazinon baits gave 70 and 60 per cent mortality of GAS respectively. Fenitrothion acted more rapidly than diazinon. Panigrahi and Raut (1993) injected dichlorvos at 1.0 ml into 15-20 g pieces of vegetable or fruit baits (*Solanum lycopersicum* Linn, *Cucumis sativus* Linn, *Trichosanthes dioica* Roxb., *Vigna unguiculate* Linn. and *Hibiscus esculentus* Linn.), against *A. fulica* and showed that the poisoned tomato and *T. dioica* was accepted by the snail and in all cases the mortality was observed after consuming the baits. Basavaraju *et al.*, (2001) recorded 100 per cent mortality of snails when they feed on baits with monocrotophos (600 ml monocrotophos 36 SL + 60 kg rice bran + 6 kg jaggeryha^{-1}) pellets under laboratory conditions. Justin *et al.*

(2008) observed that the soil application of phorate 5G @ 5 g vine^{-1} was an effective treatment in reducing the snail population infesting vanilla.

The molluscicidal activity of carbamates was due to disruption of the neurotransmitter cholinesterase (Frain 1982). In molluscs the toxicant causes rapid paralysis and loss of muscle tone (Godan 1983). Basavaraju *et al.*, (2001) observed 100 per cent mortality under laboratory conditions using carbofuran (600 g carbofuran 3G + 60 kg rice bran + 6 kg jaggery ha^{-1}) bait against GAS. He also recorded similar observations on mortality of GAS after application of methomyl based (600 ml methomyl 12.5 L + 60 kg rice bran + 6 kg jaggery ha^{-1}) bait. Shevale and Bedse (2009) recorded 70 per cent reduction in number of GAS after the application of methomyl 40SP at the rate of 10g kg^{-1} of fermented food bait (50 kg wheat bran+ 5 kg jaggery+ 1500g yeast ha^{-1}). The principal carbamates used to control terrestrial mollusc pests are carbaryl, isolan, mexacarbate, cloethocarb, methiocarb, and thiodicarb (Barker and Watts, 2002).

El-Eshra *et al.* (2016) reported 85 and 91per cent mortality of *Eobania vermiculata* Muller, a land snail pest after the application of imidacloprid and acetamiprid respectively. According to them imidacloprid and acetamiprid can be used for the management of molluscs. The application of thiamethoxam @ 200 µg L^{-1} resulted in 22.22 per cent mortality of *A. fulica*, whereas the application of which @ 400 µg L^{-1} resulted in 38.80 per cent mortality (Abog *et al.*, 2012).

Materials and Methods

3. MATERIALS AND METHODS

A study was conducted at College of Agriculture, Vellayani for the management of giant African snail, *Achatina fulica* (Bowdich) during 2014-2016.

3.1 COLLECTION AND MAINTENANCE OF GIANT AFRICAN SNAIL

The giant African snail (GAS) specimens were collected from the premises of College of Agriculture, Vellayani. Hand picking and trapping were the methodologies adopted for collection.

The collected organisms were maintained in wooden boxes of size 75 × 45 × 10 cm, and filled with soil up to 6 cm thickness. Collections were fed with mulberry and papaya leaves.

3.2 DISTRIBUTION OF GIANT AFRICAN SNAIL AND ITS NATURAL ENEMIES

A survey was conducted at selected five hot spots located in ten panchayaths of Thiruvananthapuram district by adopting trap technique. The panchayaths selected were, Vakkom, Kadakkavur, Chirayinkeezhu, Kilimanoor, Pulimath, Nagaroor, Pazhayakunnummel, Vithura, Tholikkodu and Vellarada. These locations were selected based on suggestions from the respective Agriculture officers.

In the selected locations, traps were installed in moistened mud pots of diameter 25 cm (base) and 10 cm (upper). Four such traps (with attractant bait material) were placed for an area of 200 m^2. The attractant bait includes 500 g wheat flour + 150 g jaggery + 5 g yeast and 6 per cent copper sulphate (as poison). The wheat flour, jaggery and yeast were mixed with water to attain a liquid consistency and allowed to ferment for minimum of 12 hours (Shevale and Bedse, 2009). Before transferring the bait to the pot, it was mixed with well grinded copper sulphate (6 per cent). On each location the traps were set up at the previous evening itself. The observations were taken on next day morning. The number of snails (adults and juveniles) and natural enemies were counted.

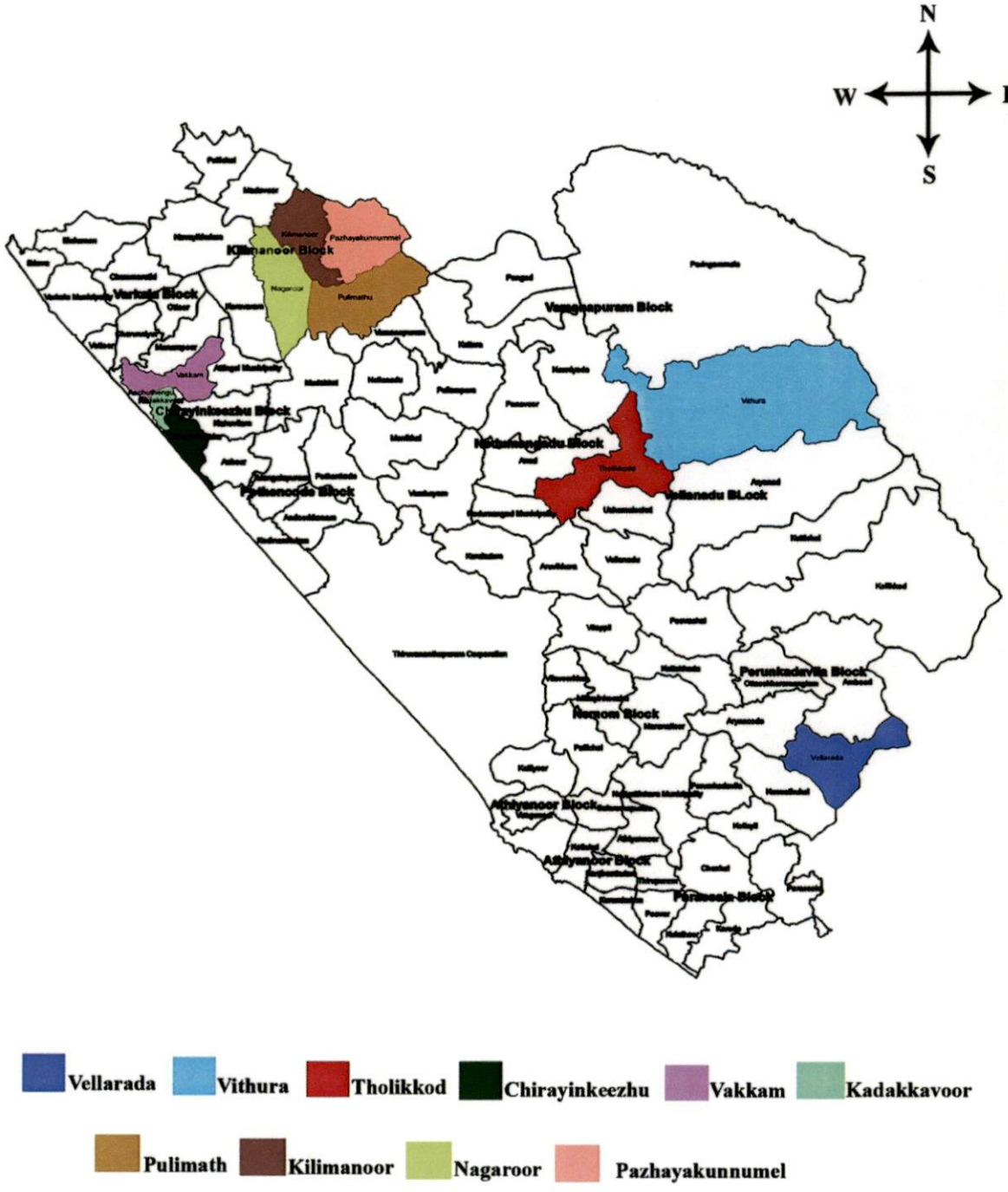


Plate 3. Panchayaths surveyed

3.3 EVALUATION OF DIFFERENT BAITS AND TRAPS FOR GIANT AFRICAN SNAIL

3.3.1 Evaluation of different baits

The study was conducted at College of Agriculture, Vellayani. Different baits were evaluated against the GAS as listed below. The experiment was conducted in CRD with six treatments and four replications. The treatments were as follows

T1 : Papaya leaf pulp (0.5kg) + jaggery (100g) + wheat flour (0.5kg)

T2 : Papaya leaf pulp (0.5kg) +jaggery (100g) + cooked rice (0.5kg)

T3 : Banana leaf pulp (0.5kg) + jaggery (100g) + wheat flour (0.5kg)

T4 : Banana leaf pulp (0.5kg) +jaggery (100g) +cooked rice (0.5kg)

T5 : Bread (100g) + jaggery (50g)

T6 : Control (wet jute sac alone)

Pits of size 1 ×1 ×1 m were dug to place traps, and wet jute sacs were placed inside the pits in such a way that it will be covered by soil up to the rim. The baits were applied as per treatments within the sacs. The number of adults and juveniles of GAS and slugs were recorded 24 Hours After Treatment (HAT) separately.

3.3.2 Evaluation of different traps

An experiment was conducted at College of Agriculture, Vellayani to select the best trap for GAS. The experiment was designed in CRD with six treatments and four replications. The treatments were as follows.

T1 : Wet jute sac with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast , copper sulphate 6 %)

T2 : Mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)

T3 : Plastic bottle (30 cm height and 10 cm diameter) with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g Yeast , copper sulphate 6 %)

T4 : Pit with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast , copper sulphate 6 %)

T5 : Wet jute sac with papaya leaves (750 g)

T6 : Control (Pit with out any bait)

The traps were installed in such a way that, the soil covered up to the rim of the pot. The traps were applied as per treatments. The number of adults and juveniles of GAS were recorded separately at twenty four, forty eight and seventy two HAT respectively.

3.4 EVALUATION OF CHEMICALS AGAINST GIANT AFRICAN SNAIL

3.4.1 Evaluation of mortality

Eight chemicals were evaluated against GAS, with water spray as check. Five uniform sized individuals were taken in a trough measuring 20 cm diameter and 10 cm height and the chemicals were applied using hand sprayer. The application was done in such a way that the spray solution should touch uniformly over exposed body parts. The design selected was CRD, with twenty-six treatments and three replications. The details of the treatments were given below.

T1 : Spinosad (Tracer 45 SC) @ 200 ppm

T2 : Spinosad (Tracer 45 SC) @ 300 ppm

T3 : Spinosad (Tracer 45 SC) @ 400 ppm

T4 : Carbosulfan (Marshal 25EC) @ 1000 ppm

T5 : Carbosulfan (Marshal 25EC) @ 2000 ppm

T6 : Carbosulfan (Marshal 25EC) @ 4000 ppm

T7 : Thiamethoxam (Actara 25 WG) @ 300 ppm

T8 : Thiamethoxam (Actara 25 WG) @ 400 ppm

T9 : Thiamethoxam (Actara 25 WG) @ 500 ppm

T10 : Common salt (sodium chloride) @ 1 %

T11 : Common salt (sodium chloride) @ 3 %

T12 : Common salt (sodium chloride) @ 6 %

T13 : Common salt (sodium chloride) @ 10 %

T14 : Copper sulphate @ 1 %

T15 : Copper sulphate @ 3 %

T16 : Copper sulphate @ 5 %

T17 : Chlorpyriphos (20 EC) @ 2 ml L^{-1}

T18 : Chlorpyriphos (20 EC) @ 4 ml L^{-1}

T19 : Chlorpyriphos (20 EC) @ 6ml L^{-1}

T20 : Copper oxychloride @ 1 %

T21 : Copper oxychloride @ 2 %

T22 : Copper oxychloride @ 4 %

T23 : Copper hydroxide @ 1 %

T24 : Copper hydroxide @ 2 %

T25 : Copper hydroxide @ 4 %

T26 : Water spray (Control)

The mortality of the snails were recorded at twenty-four, forty-eight and seventy-two HAT.

3.4.2 Evaluation of ovicidal effect of chemicals

One clutch of egg (50 numbers) was treated with thiamethoxam, spinosad, carbosulfan, copper sulphate and common salt with water spray as control.

One clutch of egg taken in a trough of size, 20 cm diameter and 10 cm height with a layer of moist soil. The eggs were exposed with chemicals as per the treatments, using a hand sprayer. CRD was the experimental design used, with twelve treatments and three replications.

T1 :Spinosad (Tracer 45 SC) @ 200 ppm

T2 :Spinosad (Tracer 45 SC) @ 300 ppm

T3 :Spinosad (Tracer 45 SC) @ 400 ppm

T4 :Carbosulfan (Marshal 25EC) @ 1000 ppm

T5 :Carbosulfan (Marshal 25EC) @ 2000 ppm

T6 :Carbosulfan (Marshal 25EC) @ 4000 ppm

T7 :Thiamethoxam (Actara 25 WG) @ 300 ppm

T8 :Thiamethoxam (Actara 25 WG) @ 400 ppm

T9 :Thiamethoxam (Actara 25 WG) @ 500 ppm

T10 : Common salt (sodium chloride) 1%

T11 : Copper sulphate 1%

T12 : Water spray

The number of eggs hatched were recorded at 8, 16, 24 and 48 days after treatment.

3.4.3 Evaluation of different poison baits against giant African snail

Different chemicals were tested against giant African snail by adopting poison bait technique. The study was conducted in Department of Agricultural Entomology, College of Agriculture, Vellayani.

Eight chemicals were evaluated against GAS. The experiment was laid out in completely randomised design with three replications. The total number of treatments were twenty-five.

3.4.3.1 Preparation of poison baits

The baits were prepared by mixing 500 g of wheat flour, 150 g of jaggery and 5 g of yeast. The ingredients were mixed thoroughly to a semi solid consistency and kept overnight for fermentation. On the next day, the fermented product was mixed with the chemicals as per treatments.

3.4.3.2 Evaluation of mortality of GAS

Five uniform sized snails were kept in a trough of size 20 × 30 × 10 cm containing a uniform layer of soil at the bottom. 200 g of the poison bait was applied to each trough.

The following were the treatments used for the experiment.

T1 : Spinosad (45 SC) @ 0.30 ml L^{-1}

T2 : Spinosad (45 SC) @ 0.60 ml L^{-1}

T3 : Spinosad (45 SC) @ 0.90 ml L^{-1}

T4 : Thiamethoxam (25 WG) @ 0.20 ml L^{-1}

T5 : Thiamethoxam (25 WG) @ 0.40 ml L^{-1}

T6 : Thiamethoxam (25 WG) @ 0.60 ml L^{-1}

T7 : Carbosulfan (25EC) @ 1.00 ml L^{-1}

T8 : Carbosulfan (25EC) @ 2.00 ml L^{-1}

T9 : Carbosulfan (25EC) @ 3.00 ml L^{-1}

T10 : Chlorpyriphos (20 EC) @ 2.00 ml L^{-1}

T11 : Chlorpyriphos (20 EC) @ 4.00 ml L^{-1}

T12 : Chlorpyriphos (20 EC) @ 6.00 ml L^{-1}

T13 : Flubendiamide (39.35% SC) @ 0.20 ml L^{-1}

T14 : Flubendiamide (39.35% SC) @ 0.30 ml L^{-1}

T15 : Flubendiamide (39.35% SC) @ 0.40 ml L^{-1}

T16 : Chlorantraliniprole (18.5SC) @ 0.20 ml L^{-1}

T17 : Chlorantraliniprole (18.5SC) @ 0.40 ml L^{-1}

T18 : Chlorantraliniprole (18.5SC) @ 0.60 ml L^{-1}

T19 : Metaldehyde @ 2.00 g m^{-2}

T20 : Metaldehyde @ 4.00 g m^{-2}

T21 : Metaldehyde @ 6.00 g m^{-2}

T22 : Copper sulphate @ 1.00 %

T23 : Copper sulphate @ 3.00 %

T24 : Copper sulphate @ 5.00 %

T25 : Untreated (Control)

The observations on the mortality of snails were taken at 24, 48 and 72 HAT and percentage mortality was calculated.

3.5 EVALUATION OF BOTANICALS AGAINST GIANT AFRICAN SNAIL

A laboratory experiment was conducted in Department of Agricultural Entomology, College of Agriculture, Vellayani, to verify the efficacy of different botanicals against GAS. The leaf extracts of *Piper nigrum*, *Solanum nigrum, Azadirachta indica, Clerodendron infortunatum, Lantana camara* and seed extract of *Annona squamosa* and *A. indica* were evaluated to verify the molluscicidal, ovicidal and antifeedant activity against GAS (Plate 3).

3.5.1 Preparation of fresh aqueous leaf extracts of plants

The fresh leaves collected were separately washed with clean water thoroughly and chopped into small pieces. Hundred gram of chopped leaves were macerated in an electric blender and mixed with 100 ml of distilled water and kept overnight at room temperature. The mixture was then filtered with cheese cloth followed by Whatmann No.1 filter paper. The volume of the filtrate was made up to 100ml to prepare the stock solution. Different concentrations *viz.* 5, 10 and 15 per cent were prepared from the stock solution up on dilution with distilled water.

3.5.2 Preparation of seed extract

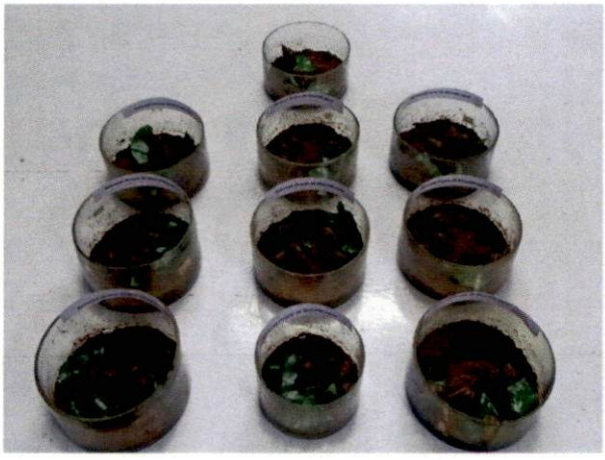
Seeds of *A. squamosa* and *Azadirachta indica* were ground to a coarse powder using an electric blender. Twenty gram of the powdered material was taken in a muslin cloth bag and tied. This was dipped in 500 ml of distilled water and kept overnight. The cloth bag was squeezed well to collect the extract. It was then made up to one litre to get two per cent aqueous extract. Similarly, other concentrations were also prepared.

a) *Clerodendron infortunatum*

b) *Azadirachta indica*

c) *Lantana camara*

d) Botanicals evaluated



e) GAS treated with botanicals

Plate 4. Evaluation of botanicals against giant African snail

3.5.3 Evaluation of mortality

Five uniform sized GAS were selected and taken in a trough measuring 20 cm diameter and 10 cm height. Fresh leaf extracts were sprayed over the exposed body parts of GAS. The experiment was laid out in CRD, with sixteen treatments, replicated thrice, including water spray as check. The treatments used were as follows

T1 : *P. nigrum* leaf extract @ 5 %

T2 : *P. nigrum* leaf extract @ 10 %

T3 : *P. nigrum* leaf extract @ 15 %

T4 : *S. nigrum* leaf extract @ 5 %

T5 : *S. nigrum* leaf extract @ 10 %

T6 : *S. nigrum* leaf extract @ 15 %

T7 : *A. indica* leaf extract @ 5 %

T8 : *A. indica* leaf extract @ 10 %

T9 : *A. indica* leaf extract @ 15 %

T10 : *C. infortunatum* leaf extract @ 5 %

T11 : *C. infortunatum* leaf extract @ 10 %

T12 : *C. infortunatum* leaf extract @ 15 %

T13 : *A. squamosa* seed extract @ 2 %

T14 : *A. squamosa* seed extract @ 4 %

T15 : *A. squamosa* seed extract @ 8 %

T16 : Water spray (Control)

The observation on mortality of GAS was recorded at 24 and 72 hours after treatment.

3.5.4 Evaluation of ovicidal effect

One clutch of egg (50 numbers) treated with leaf extracts of *P. nigrum*, *S. nigrum, A. indica, C. infortunatum* and seed extract of *A. squamosa.* The extracts were prepared as per the methodologies discussed in 3.5.1 and 3.5.2.

Eggs were kept in a trough of size 20 cm diameter and 10 cm height with a layer of moist soil. The eggs were exposed to botanicals as per the treatments, using a hand sprayer. The experiment was designed in CRD, with sixteen treatments replicated thrice. The treatments were as follows,

T1 : *P. nigrum* leaf extract @ 5 %

T2 : *P. nigrum* leaf extract @ 10 %

T3 : *P. nigrum* leaf extract @ 15 %

T4 : *S. nigrum* leaf extract @ 5 %

T5 : *S. nigrum* leaf extract @ 10 %

T6 : *S. nigrum* leaf extract @ 15 %

T7 : *A. indica* leaf extract @ 5 %

T8 : *A. indica* leaf extract @ 10 %

T9 : *A. indica* leaf extract @ 15 %

T10 : *C. infortunatum* leaf extract @ 5 %

T11 : *C. infortunatum* leaf extract @ 10 %

T12 : *C. infortunatum* leaf extract @ 15 %

T13 : *A. squamosa* seed extract @ 2 %

T14 : *A. squamosa* seed extract @ 4 %

T15 : *A. squamosa* seed extract @ 8 %

T16 : Water spray (Control)

The number of eggs hatched were recorded at 8, 16, 24 and 48 days after treatment.

3.5.5 Evaluation of antifeedant effect

The methodology followed was no-choice assay suggested by Bentley *et al.* (1984). Papaya leaf discs of size 15 cm diameter were sprayed with leaf extracts of *P. nigrum*, *S. nigrum, A. indica, C. infortunatum* and *L. camara* and seed extracts of *A. indica* and *A. squamosa* as per treatments. It was then air dried and allowed to feed by GAS. The extracts were prepared as per the methodologies discussed in 3.5.1 and 3.5.2.

Three uniform sized snails starved for 48 hours were taken in a trough of size 25 cm diameter × 10 cm height and were allowed to feed on the papaya leaf discs. The experiment was laid out in CRD with sixteen treatments, replicated thrice. The treatments were as follows,

T1 : *P. nigrum* leaf extract @ 5 %

T2 : *P. nigrum* leaf extract @ 10 %

T3 : *P. nigrum* leaf extract @ 15 %

T4 : *S. nigrum* leaf extract @ 5 %

T5 : *S. nigrum* leaf extract @ 10 %

T6 : *S. nigrum* leaf extract @ 15 %

T7 : *A. indica* leaf extract @ 5 %

T8 : *A. indica* leaf extract @ 10 %

T9 : *A. indica* leaf extract @ 15 %

T10 : *C. infortunatum* leaf extract @ 5 %

T11 : *C. infortunatum* leaf extract @ 10 %

T12 : *C. infortunatum* leaf extract @ 15 %

T13 : *A. squamosa* seed extract @ 2 %

T14 : *A. squamosa* seed extract @ 4 %

T15 : *A. squamosa* seed extract @ 8 %

T16 : *A. squamosa* seed extract @ 15 %

T17 : *A. indica* seed extract @ 4 %

T18 : *A. indica* seed extract @ 8 %

T19 : *A. indica* seed extract @ 15 %

T20 : *L. camara* leaf extract @ 10 %

T21 : *L. camara* leaf extract @ 15 %

T22 : *L. camara* leaf extract @ 25 %

T23 : Water spray (Control)

The observations were recorded at two-hourly interval up to 8 hours of treatment. The leaf area consumed was computed by plotting it in a graph paper. Based on the area consumed, the per cent leaf area protection was calculated using the formula suggested by Bentley *et al.* (1984).

$$\text{Per cent leaf area protection} = \frac{\text{Leaf area (L.A) consumed in control} - \text{L.A consumed in treatment} \times 100}{\text{Leaf area consumed in control}}$$

3.6 EVALUATION OF PATHOGENIC NEMATODES AGAINST GIANT AFRICAN SNAIL

Two species of pathogenic nematodes belonging to the genus Heterorhabditis *viz. Heterorhabditis bacteriophora* Poiner., *Heterorhabditis indica* Poiner three species of the genus Steinernema *viz. Steinernema abbasi* Elawad, Ahmad and Reid, *Steinernema bicornutum* Tallosi, Peters and Ehlers, *Steinernema carpocapsae* Weiser and two species of the genus *Rhabditis* were evaluated against GAS under *in vitro* conditions. The nematode culture was obtained from Banana Research Station, Kannara, and from the Department of Nematology, College of Agriculture, Vellayani.

3.6.1 Culturing of pathogenic nematodes

The nematodes were cultured in wax moth, *Galleria mellonella* Linn. larvae. Infected *G. mellonella* were kept in white trap (Bedding and Akhurst, 1975) to obtain the infective juveniles. The infective juveniles were collected from the white trap using distilled water, counted and were applied as per treatments to the snails.

3.6.2 Evaluation of mortality

Five uniform sized GAS were kept in a trough of size 20 × 13 × 10 cm, with a thin layer of soil in it. Pathogenic nematodes were applied to the snails as per treatments. The experiment was designed in CRD with three replications (Plate 4).

T1 : *H. bacteriophora* @ 500 IJ Snail^{-1}

T2 : *H. bacteriophora* @ 1000 IJ Snail^{-1}

T3 : *H. bacteriophora* @ 3000 IJ Snail^{-1}

T4 : *H. indica* @ 500 IJ Snail^{-1}

T5 : *H. indica* @ 1000 IJ Snail^{-1}

T6 : *H. indica* @ 3000 IJ Snail^{-1}

T7 : *S. abbasi* @ 500 IJ Snai^{-1}

T8 : *S. abbasi* @ 1000 IJ Snail^{-1}

T9 : *S. abbasi* @ 3000 IJ Snail^{-1}

T10 : *S. bicornutum* @ 500 IJ Snail^{-1}

T11 : *S. bicornutum* @ 1000 IJ Snail^{-1}

T12 : *S. bicornutum* @ 3000 IJ Snail^{-1}

T13 : *S. carpocapsae* @ 500 IJ snail^{-1}

T14 : *S. carpocapsae* @ 1000 IJ snail^{-1}

T15 : *S. carpocapsae* @ 3000 IJ snail^{-1}

T16 : *Rhabditis* sp. @ 500 IJ snail^{-1}

T17 : *Rhabditis* sp. @ 1000 IJ snail^{-1}

T18 : *Rhabditis* sp. @ 3000 IJ snail^{-1}

T19 : *Rhabditis* sp. @ 500 IJ snail^{-1}

T20 : *Rhabditis* sp. @ 1000 IJ snail^{-1}

T21 : *Rhabditis* sp. @ 3000 IJ snail^{-1}

T22 : Water spray (Control)

The mortality was observed at 24 and 72 hours after treatment.

a) GAS treated with *S. bicornatum*

b) GAS treated with *S. carpocapsae*

c) GAS treated with *H. indica*

d) GAS treated with *H. bacteriophora*

e) GAS treated with *S. abbasi*

Plate 5. Evaluation of pathogenic nematodes against giant African snail

3.7 EVALUATION OF DIFFERENT ENTOMOPATHOGENIC FUNGI AGAINST GIANT AFRICAN SNAIL

Three different entomopathogenic fungi were tested against GAS Viz. *Lecanicillium lecanii* Zare and Gams, *Metarhizium anisopliae* Metschn. and *Beauveria bassiana* Bals-criv with a spore concentration of 10^7, 10^8 and 10^8 spores ml^{-1} respectively. The spore suspension was obtained from Biocontrol laboratory, College of Agriculture, Vellayani. The spore count of suspension was measured using Neubaeurs haemocytometer.

Five uniform sized snails were taken in a trough of size, 20 × 30 × 10 cm. the snails were treated with the spore suspension of entomopathogenic fungi.

Two experimental methodologies *viz.* topical application and leaf dip method were followed. In topical application, the spore suspension was pipetted out and applied directly on the organism. Whereas in leaf dip method, the spore suspension was applied over the leaf which was used as feed of GAS. The experiment was laid out in CRD with six treatment combinations replicated four times.

3.8 STATISTICAL ANALYSIS

Observations recorded from laboratory and field were converted in to data and were analysed using one way analysis of variance (ANOVA) after subjected to necessary transformations (Panse and Sukhatme, 1967).

Results

4. RESULTS

The results of study entitled" Management of giant African snail, *Achatina fulica* (Bowdich)" conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani during 2014-16 are presented here.

4.1 DISTRIBUTION OF GIANT AFRICAN SNAIL AND ITS NATURAL ENEMIES

4.1.1 Distribution of giant African snail

In order to study the distribution of giant African snail (GAS), a survey was conducted in five selected hotspots, located in ten panchayaths of Thiruvananthapuram district. The mean number of adults and juveniles of GAS collected from an area of 200 m^2 were represented in Table 1.

Among the ten panchayaths surveyed, the highest number of adult GAS were recorded from Pulimath panchayath (19.50) followed by Vakkom (17.65) and Vellarada panchayaths (14.25). The lowest number of adults were collected from Tholikkode (6.05) panchayath followed by Chirayinkeezhu (6.40) panchayath. The adult population of other panchayaths *viz.* Kilimanoor, Nagaroor, Vithura, Pazhayakunnummel, Kadakkavoor were 12.95, 8.20, 7.55, 7.50 and 7.25 respectively.

Vakkom panchayath recorded the highest population of juvenile GAS (15.45), followed by Vellarada (12.75) and Pulimath (12.35). The lowest number of juveniles were obtained from Tholikkode (5.50) panchayath. The juvenile population of GAS recorded from other panchayaths *viz.* Vithura, Nagaroor, Chirayinkeezhu, Pazhayakunnummel, Kilimanoor and Kadakkavur were 7.65, 7.60, 7.55, 7.25, 6.25 and 5.60 respectively.

Among different locations of Vakkom panchayath, the highest population of adult and juveniles of GAS were recorded from Vakkom (21.50) and

Table 1. Distribution of giant African snail in Thiruvananthapuram district

Panchayath	Location	Number of individuals trapped 200 m^{-2}	
		Adult	Juvenile
Vakkom	Vakkom	21.50	9.75
	Mukkaluvattom	15.50	14.75
	Moonnalumudu	18.75	18.50
	Chettithodi	17.75	17.50
	Kunjanvilakam	14.75	16.75
Chirayinkeezhu	Pazhanjira	6.50	7.00
	Chirayinkeezhu	6.25	6.75
	Kottappuram	4.75	8.50
	Anathalavattom	7.50	9.75
	Valiyakada	7.00	5.75
Kadakkavoor	Sankaramangalam	11.00	5.50
	Vilayilmoola	2.50	4.75
	Thekkumbhagam	8.75	5.75
	Nilakkamukku	8.00	7.50
	Mananakku	6.00	4.50
Pulimath	Aranthanam	27.75	17.50
	Pullayil	15.75	9.50
	Karette	19.50	12.50
	Koyyakkada	10.00	8.75
	Koduvazhannur	24.50	13.50
Kilimanoor	Allathukaavu	14.75	3.00
	Ponganadu	9.00	8.75
	Choottayil	15.75	8.00
	Deveswaram	12.50	5.25
	Palace	12.75	6.25
Nagaroor	Ramanallurkkonam	6.00	3.25
	Chenkikkunnu	11.75	10.50
	Perur	6.75	8.00
	Keezhperur	7.00	6.50
	Pavoorkkonam	9.50	9.75

Pazhayakunnummel	Vandannoor	6.75	6.75
	Thattathumala	8.50	8.25
	Pazhayakunnummel	8.25	9.75
	Chembakassery	3.75	3.75
	Tholikkuzy	10.25	7.50
Tholikkodu	Tholikkodu	7.25	3.25
	Kaniyaramcodu	7.00	8.75
	Chettiyambara	5.50	4.00
	Thottumukku	4.00	5.75
	Pulichamala	6.50	5.75
Vithura	Vithura	9.00	9.50
	Koppam	8.50	8.75
	Chennanpara	4.50	5.25
	Theviyodu	8.00	7.75
	Anappara	7.75	7.00
Vellarada	Vellarada	10.75	5.50
	Irinjinampally	18.50	17.75
	Anjumaramkaala	17.75	15.75
	Vencodu	8.25	15.50
	Arattukuzhi	15.75	8.50

Figures are the mean of four replications

Moonnalummudu (18.50) areas. Whereas the lowest number of adults and juveniles were collected from Kunjanvilakam (14.75) and Vakkom (9.75) respectively.

In the case of Chirayinkeezhu panchayath the highest number of adults and juveniles were recorded from Anathalavattom with a population of 7.50 and 9.75 individuals respectively. Whereas the lowest number of adults and juveniles were recorded from Kottappuram (4.75) and Valiyakada (5.75).

Sankaramangalam area of Kadakkavur panchayath recorded the highest number of adults (11.00) whereas Nilakkamukku area recorded the highest number of juveniles (7.50). The lowest number of adults and juveniles were reported from Vilayilmoola (2.50) and Mananakku area (4.50) respectively.

The highest number of adults and juveniles were collected from Aranthanam area of pulimath panchayath. with a population of 27.75 and 17.50 respectively. Whereas the lowest number of adults (10.00) and juveniles (8.75)were recorded from Koyyakkada area.

In the case of Kilimanoor panchayath, the location Chootayil recorded the highest population of adult GAS (15.75), whereas ponganadu recorded the highest number of juveniles (8.75). In contrast, the same area recorded the lowest population of adults (9.00). However, Alathukavu area recorded the lowest number of juveniles (3.00).

Chenkikunnu area of Nagaroor panchayath recorded the highest population of both adults (11.75) and juveniles (10.50) of GAS. Whereas Ramanallurkonam recorded the lowest population of both adults (6.00) and juveniles (3.25).

Among different locations of Pazhayakunnummel panchayath, Tholikuzhyarea showed highest population of adult GAS (10.25) and Pazhayakunnummel area recorded that for juveniles (9.75) respectively. However, the

lowest population of adults and juveniles were recorded from Chembakassery area (3.75).

In Tholikkodu panchayath, Tholikkodu location showed the highest population of adult GAS (7.25) and Kaniyaramcodu (8.75) location recorded the highest population of juveniles. The lowest population of adults were collected from Thottumukku (4.00) and juveniles from Tholikkodu (3.25)respectively.

Among the locations within Vithura panchayath, Vithura area showed a highest population of adults (9.00) and juveniles (9.50). Whereas the lowest population of adults (4.50) and juveniles (5.25) were reported from Chennanpara area.

In the case of Vellarada panchayath, highest population of adults (18.50) and juveniles (17.75) were recorded from Irinjinampally area. While the lowest population was observed from Vencodu (8.25) and Vellarada (5.50) for adults and juveniles respectively.

Among the ten panchayaths surveyed, Aranthanam of Pulimath panchayath documented the highest population of adult GAS (27.75) followed by Koduvazhannur (24.50) area of Pulimath and Vakkomarea of Vakkom panchayaths respectively. Lowest population of adults were observed from Vilayilmoola (2.50) of Kadakkavurpanchayath followed by Chembakassery (3.75) of Pazhayakunnummel and Thottumukku (4.00) of Tholikkodu panchayaths, respectively. The highest population of juvenile GAS was recorded from Moonalummud (18.50) of Vakkom panchayath followed by Irinjinampally (17.75) of Vellarada, Chettithodi (17.50) of Vakkomand Mananakku (17.50) of Kadakkavur panchayaths respectively. The lowest population of juveniles were recorded from Alathukavu (3.00) of Kilimanurpanchayath followed by Ramanallurkonam (3.25) of Nagaroorand Tholikkodu (3.25) area of Tholikkodu panchayaths, respectively.

4.1.2 Natural enemies

The population of natural enemies associated with GAS were also studied during the survey. The invertebrate predators recorded were, flat headed worm, fire fly larvae, and red ant. Whereas, the vertebrate predators recorded were house rat and birds like crow pheasant and tree pie (Table 2).

In the case of invertebrates the flat headed worm or the hammer headed worm, *Bipalium* sp., was found feeding on GAS. Among arthropods grub of firefly and red ant *Oecophylla smaragdina* Fabricius were recorded as natural enemies of GAS during the course of study.

Among the vertebrates,birds like crow pheasant, *Centropus sinensis* Stephens and tree pie, *Dendrocitta vagabunda* Latham were recorded as predators of GAS. House rat, *Rattus rattus* Linn. was also found predating on the adults and juveniles of GAS.

4.1.3 Other snails and slugs

During the survey, four species of snails, (other than *A. fulica*)and two species of slugs were also documented (Table 3). Both the snails and slugs identified were found feeding on different crops such as, banana, orchids, anthurium, portulaca, and succulent plants.

Four species of snails were identified during the course of study. They were, *Ariophanta bistrialis* Des Moulins, *Opeas gracile* Albers and *Macrochlamys* sp. Whereas the slugs identified were, *Mariella dussumieri* Grayand *Laevicaulis alte* Ferrusac.

Table 2. Natural enemies of *A. fulica* recorded during the survey

Sl no	Common name	Phylum	Class	Order	Family	Genus	Species
	a) Invertebrates						
1	Flat headed worm	Platyhelminthes	Rhabditophora	Tricladida	Geoplanidae	*Bipalium*	sp.
2	Fire fly (grub)	Arthropoda	Insecta	Coleoptera	Lampyridae		
3	Red ant	Arthropoda	Insecta	Hymenoptera	Formicidae	*Oecophylla*	*smaragdina*
	b) Vertebrates						
4	Crow pheasant	Chordata	Aves	Cuculiformes	Cuculidae	*Centropus*	*sinensis*
5	Tree pie	Chordata	Aves	Passeriformes	Corvidae	*Dendrocitta*	*vagabunda*
6	House rat	Chordata	Mammalia	Rodentia	Muridae	*Rattus*	*rattus*

Table 3. snails and slugs recorded during the survey

Sl. No.	Scientific name	Class	Order	Family
	a) Snails			
1	*Ariophanta bistrialis*	Gastropoda	Stylommatophora	Ariophantidae
2	*Opeas gracile*	Gastropoda	Stylommatophora	Subulinidae
3	*Macrochlamys* sp.	Gastropoda	Stylommatophora	Ariophantidae
	b) Slugs			
4	*Mariella dussumieri*	Gastropoda	Stylommatophora	Ariophantidae
5	*Laevicaulis alte*	Gastropoda	Stylommatophora	Veronicellidae

4.2 EVALUATION OF DIFFERENT BAITS AND TRAPS FOR GIANT AFRICAN SNAIL

4.2.1 Evaluation of different baits for giant African snail

Among the different baits evaluated for adult GAS, T1 [Papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg)] was found significantly superior to other treatmens with a population of 11.65 followed by T2 [Papaya leaf pulp (0.5 kg) + jaggery (100 g) + cooked rice (0.5 kg)]with a population of 7.15 and T3 [Banana leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg)]witha population of 4.52 respectively. However, both the treatments were on par with each other. The treatmentT4 [Banana leaf pulp (0.5 kg) + jaggery (100 g) + cooked rice (0.5 kg)] recorded the lowest population of adults (2.12). However, it was found to be non-significant. when compared to control (0.22) (Table 4).

In the case of juveniles of GAS attracted, the treatment T1 was identified as the best bait with a population of 6.62 followed by T2 (4.52) and T3 (2.70) respectively. The treatment T1 was statistically on par with T2 and T2 with that of T3. The treatment T4 with a population of 0.97 was observed as least effective bait for juveniles. The treatments T1, T2 and T3 were statistically significant over control (0.15). However, all other treatments were found to be non-significant compared to control.

The treatment T1wasfound to be the best bait for slugs, with a population of 3.22 followed by treatment T2 with a population of 2.20. However, both the treatments were found on par with each other.The treatment T4 (0.62) was found as the least effective bait for slugs. The treatments T1, T2 and T5 (1.55) were statistically superior to control (0.00). However, all other treatments were nonsignificant.

Table 4. Evaluation of different baits for GAS

Treatments	Number of individuals attracted		
	Adult GAS	Juvenile GAS	Slugs
T1 Papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg)	11.65[a]	6.62a	3.22[a]
T2 Papaya leaf pulp (0.5 kg) + jaggery (100 g) + cooked rice (0.5 kg)	7.15[b]	4.52[ab]	2.20[ab]
T3 Banana leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg)	4.52[bc]	2.70[bc]	1.05[bcd]
T4 Banana leaf pulp (0.5 kg) + jaggery (100 g) + cooked rice (0.5 kg)	2.12[cd]	0.97[cd]	0.62[cd]
T5 Bread (100 g) + jaggery (50 g)	3.65[c]	1.70[cd]	1.55[bc]
T6 (Control) without any bait	0.22[d]	0.15[d]	0.00[d]
CD (0.05)	3.273	2.459	1.521

Figures are the mean of four replications

Values with different letters are significantly different from each other by DMRT at 5 % level

4.2.2 Evaluation of different traps for giant African snail

4.2.2.1 First day after exposure to different traps

The results revealed that, treatments T1 [Wet jute sac with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)]and T5 [Wet jute sac with papaya leaves (750 g)] were found to be the best treatments in trapping the snails with 15.25 and 14.25 number of snails trapped treatment^{-1}respectively, followed by T2 [Mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)] (14.00). However, all the treatments were on par with each other. The treatment T4 [Pit with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)] (7.25) trapped lowest number of snails treatment^{-1}. All treatments found statistically superior to control (1.00) (Table 5).

4.2.2.2 Second day after exposure to different traps

The treatments T1 and T2 were the best treatments in trapping the snails with number of snails trapped treatment^{-1} as 19.00 and21.50 respectively, followed by T5 (17.75). However, all the traetments were on par with each other.The treatment T4 showedthe lowest number of GAS trap^{-1}. However, all the treatments were statistically superior to control (1.50).

4.2.2.3 Third day after exposure to different baits

The observations of day 3 revealed that, only the treatment T2 (17.00) was found significantly superior to all other treatments in trapping the snails followed by T5 (12.50) and T3 [Plastic bottle (30 cm height and 10 cm diameter) with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)] (11.75). The treatment T4 (5.25)recorded the lowest number of snails. However, all the treatments were superior to control (0.75).

Table 5. Evaluation of different traps for GAS

Treatments	Mean number of GAS trapped			
	Day 1	**Day 2**	**Day 3**	**Total**
T1 Wet jute sac with fermented bait*and poison#	14.25 (3.81)^{a}	19.00 (4.40)^{a}	7.50 (2.82)^{c}	13.16 (3.59)^{b}
T2 Mud pot with fermented bait*and poison#	14.00 (3.80)^{ab}	21.50 (4.68)^{a}	17.00 (4.18)^{a}	20 (4.46)^{a}
T3 Plastic bottle with fermented bait*and poison#	10.75 (3.34)^{b}	14.25 (3.81)^{bc}	11.75 (3.49)^{b}	10.33 (2.94)^{c}
T4 Pit with fermented bait*and poison#	7.25 (2.77)^{c}	10.50 (3.30)^{c}	5.25 (1.89)^{d}	7.66 (2.74)^{c}
T5 Wet jute sac with papaya leaves	15.25 (3.95)^{a}	17.75 (4.29)^{ab}	12.50 (3.60)^{b}	13.25 (3.62)^{b}
T6 (Control) Pit with out any bait	1.00 (1.12)^{d}	1.50 (1.36)^{d}	0.75 (1.09)^{e}	1.08 (1.03)^{d}
CD (0.05)	(0.485)	(0.527)	(0.323)	(0.665)

Figures in parentheses are $\sqrt{X+1}$ transformed Mean of three replications.

Values with different letters are significantly different from each other by DMRT at 5 % level

*- 500 g Wheat flour + 200 g Jaggery + 5 g Yeast

- Copper sulphate 6 %

4.3 EVALUATION OF CHEMICALS AGAINST GIANT AFRICAN SNAIL

4.3.1 Evaluation of mortality

On perusal of the data recorded in Table 6, it was observed that, among the seven chemicals evaluated against GAS, only five were effective in causing mortality.

4.3.1.1 Per cent mortality of GAS at twenty-four hours after treatment (HAT)

The highest mortality of 46.66 per cent was recorded by the application of copper sulphate 5 % and it was statistically on par with the results obtained by the application of copper hydroxide 4 % (40.00) followed by copper oxychloride 4 % and common salt (sodium chloride) 10 % with a mortality of 33.33 per cent. Copper hydroxide 2 % showed 26.66 per cent mortality and it was on par with copper oxychloride 4% and common salt 10 %. No significant variation was observed in the mortality exhibited by copper hydroxide 2 % and copper oxychloride 2 %. The treatments including two concentrations of copper sulphate (1% and 3%), three concentrations of chlorpyriphos (20 EC) (2 ml L^{-1}, 4 ml $L^{-1}$and 6 ml L^{-1}) copper oxychloride 1 % and copper hydroxide 1 % were ineffective to cause mortality of snails. They were statistically inferior to control.

4.3.1.2 Per cent mortality of GAS at fourty-eight HAT

As the exposure time increased from twenty-four to fourty-eight hours, the copper sulphate 5 % exhibited a mortality of 73.33 per cent and it was found statistically on par with that exhibited by the application of copper hydroxide 4 % (66.66) and copper oxychloride 4 % (60.00) respectively. Mortality of 33.33 per cent was recorded by the application of common salt 10 %, copper hydroxide 2 % and copper sulphate 3 % and all these treatments were found statistically on par with copper oxychloride 2 % and chlorpyriphos 6 ml L^{-1} with 20 per cent mortality.

Table 6. Effect of different chemicals on the mortality of giant African snail

Treatments	Percentage mortality		
	24 HAT	48 HAT	72 HAT
Common salt (sodium chloride) @ 1 %	0.00 (1.28)^{e}	0.00 (1.28)^{c}	0.00 (1.28)^{e}
Common salt (sodium chloride) @ 5 %	0.00 (1.28)^{e}	0.00 (1.28)^{c}	0.00 (1.28)^{e}
Common salt (sodium chloride) @ 10 %	33.33 (35.00)^{bc}	33.33 (35.00)^{b}	33.33 (35.00)^{cd}
Copper sulphate @ 1 %	0.00 (1.28)^{e}	6.66 (9.70)^{c}	20.00 (26.56)^{d}
Copper sulphate @ 3 %	0.00 (1.28)^{e}	33.33 (35.00)^{b}	46.66 (43.07)^{c}
Copper sulphate @ 5 %	46.66 (43.07)^{a}	73.33 (59.21)^{a}	93.33 (80.29)^{a}
Chlorpyriphos (20 EC) @ 2 ml L^{-1}	0.00 (1.28)^{e}	0.00 (1.28)^{c}	0.00 (1.28)^{e}
Chlorpyriphos (20 EC) @ 4 ml L^{-1}	0.00 (1.28)^{e}	0.00 (1.28)^{c}	6.66 (9.70)^{e}
Chlorpyriphos (20 EC) @ 6 ml L^{-1}	0.00 (1.28)^{e}	20.00 (26.56)^{b}	33.33 (35.00)^{cd}
Copper oxychloride @ 1 %	0.00 (1.28)^{e}	0.00 (1.28)^{c}	0.00 (1.28)^{e}
Copper oxychloride @ 2 %	20.00 (26.56)^{d}	20.00 (26.56)^{b}	20.00 (26.56)^{d}
Copper oxychloride @ 4 %	33.33 (35.00)^{bc}	60.00 (50.76)^{a}	80.00 (63.43)^{b}
Copper hydroxide @ 1 %	0.00 (1.28)e	6.66 (9.70)^{c}	6.66 (9.70)^{e}
Copper hydroxide @ 2 %	26.66 (30.78)^{cd}	33.33 (35.00)^{b}	46.66 (43.07)^{c}

Copper hydroxide @ 4 %	40.00 (39.23)^{ab}	66.66 (54.99)^{a}	80.00 (63.43)^{b}
Control	0.00 (1.28)^{e}	0.00 (1.28)^{b}	0.00 (1.28)^{e}
CD (0.05)	(6.961)	(12.811)	(14.054)

Figures in parentheses are arc sin transformed. Mean of three replications.

Values with different letters are significantly different from each other by DMRT at 5 % level

The treatments *viz.* chlorpyriphos 2ml L^{-1}, 4 ml L^{-1} and copper oxychloride 1% were ineffective to cause mortality of GAS even after forty-eight hours of exposure. However, a non-significance with control was exhibited by the treatments *viz.* copper sulphate 1%, chlorpyriphos 2 ml L^{-1}, chlorpyriphos 4 ml L^{-1}, copper oxychloride 1% and copper hydroxide 1%.

4.3.1.3 Per cent mortality of GAS at seventy-two HAT

Significantly higher percentage mortality (93.33) was shown by copper sulphate 5 %,followed by copper oxychloride 4 % (80.00) and copper hydroxide at 4 % (80.00) and were statistically on par with each other. No significant variation was observed in the effect exhibited by copper hydroxide 2 %, copper sulphate 3 %, common salt 10 % and chlorpyriphos 6 ml/L and mortality in the above treatments ranged from 33.33 to 46.66 per cent. Statistically significant variation was observed in the mortality exhibited by copper oxychloride at 4% and 2 % concentration, which recorded 80 and 20 per cent mortality respectively. Chlorpyriphos at the concentration of 6 ml/L exhibited 33.33 per cent mortality, while 6.66 per cent mortality was recorded by the application of chlorpyriphos 4 ml/L and the two treatments differed significantly in their performance. The treatments *viz.* Chlorpyriphos 2 ml L^{-1} and copper oxychloride 1% were unable to cause mortality of GAS. However, the treatments *viz.* Chlorpyriphos 2 ml L^{-1}, chlorpyriphos 4 ml L^{-1}, copper oxychloride 1% and copper hydroxide 1% showed a non-significance to control.

4.3.2 Evaluation of ovicidal effect

Ovicidal effect of different chemicals were studied in the laboratory. Among the three chemicals evaluated, none of them exhibited any ovicidal action.

4.3.3 Evaluation of chemicals as poison baits

4.3.3.1 Per cent mortality of GAS at twenty-four HAT

Application of copper sulphate 5 % recorded significantly higher per cent mortality (93.33) of GAS followed by carbosulfan (25 EC)@ 3 ml L^{-1} (73.33). Application of spinosad (45 SC) @0.90 ml L^{-1} (66.66) and 0.60 ml L^{-1} (53.33) were statistically on par with each other. However, the lowest concentration of the same chemical *i.e*0.30 ml L^{-1} (26.66) was significantly different from its higher concentrations. The three different concentrations of copper sulphate *viz.,* 1%, 3% and 5 % showed statistically significant variation among each other and the percentage mortality of GAS in these treatments were 40.00, 66.66 and 93.33 respectively. No significant variation in per cent mortality was observed after the application of chlorpyriphos (20 EC)4 ml L^{-1} (40.00) and 6 ml L^{-1}(60.00). However, the treatments showed statistical variation by the application of its lower concentration, 2 ml L^{-1}(20.00 %). Metaldehyde @ 6 g m^{-2} and 4 g m^{-2}showed 60.00 and 20.00 per cent mortality of GAS while its lower concentration (2 g m^{-2}) was ineffective to cause mortality. The application of thiamethoxam (25 WG) @ 0.40 ml $L^{-1}$and 0.60 ml L^{-1}were statistically significant with each other *i.e*, 13.33 and 26.66 per cent mortality respectively. However, thiamethoxam @ 0.20 ml $L^{-1}$was ineffective to cause mortality of GAS. Flubendiamide (39.35% SC) (0.20, 0.30 and 0.40 ml L^{-1}) and chlorantraniliprole (18.5 SC) (0.20, 0.40 and 0.60 ml L^{-1}) showed no mortality of GAS. Hence, the treatments *viz.* thiamethoxam 0.20 ml L^{-1}, flubendiamide 0.20ml L^{-1}, 0.30 ml L^{-1}, 0.40 ml L^{-1}, chlorantraniliprole 0.20 ml L^{-1}, 0.40 ml L^{-1}, 0.60 ml L^{-1} and metaldehyde 2 g m^{-2} were non-significant when compared to control (Table 7).

Table 7. Effect of different chemicals as poison baits against giant African snail

Treatments	Percentage mortality		
	24 HAT	48 HAT	72 HAT
Spinosad (45 SC) @ 0.30 ml L^{-1}	26.66 $(30.78)^{ef}$	40.00 $(38.85)^{efg}$	66.66 $(54.99)^{cde}$
Spinosad (45 SC) @ 0.60 ml L^{-1}	53.33 $(46.92)^{bcd}$	80.00 $(67.64)^{bc}$	100.00 $(88.71)^{a}$
Spinosad (45 SC) @ 0.90 ml L^{-1}	66.66 $(54.99)^{b}$	93.33 $(80.29)^{ab}$	100.00 $(88.71)^{a}$
Thiamethoxam (25 WS) @ 0.20 ml L^{-1}	0.00 $(1.28)^{h}$	13.33 $(18.13)^{h}$	26.66 $(30.78)^{ij}$
Thiamethoxam (25 WS) @ 0.40 ml L^{-1}	13.33 $(18.13)^{g}$	40.00 $(38.85)^{efg}$	53.33 $(46.92)^{efg}$
Thiamethoxam (25 WS) @ 0.60 ml L^{-1}	26.66 $(30.78)^{ef}$	46.66 $(43.07)^{defg}$	80.00 $(63.43)^{bc}$
Carbosulfan (25EC) @ 1.00 ml L^{-1}	33.33 $(35.00)^{def}$	46.66 $(43.07)^{defg}$	86.66 $(71.86)^{b}$
Carbosulfan (25EC) @ 2.00 ml L^{-1}	53.33 $(46.92)^{bcd}$	66.66 $(54.99)^{cde}$	100.00 $(88.71)^{a}$
Carbosulfan (25EC) @ 3.00 ml L^{-1}	73.33 $(59.21)^{b}$	93.33 $(80.29)^{ab}$	100.00 $(88.71)^{a}$
Chlorpyriphos (20 EC) @ 2.00 ml L^{-1}	20.00 $(26.56)^{fg}$	33.33 $(35.00)^{fg}$	46.66 $(43.07)^{fgh}$
Chlorpyriphos (20 EC) @ 4.00 ml L^{-1}	40.00 $(39.23)^{cde}$	53.33 $(46.92)^{def}$	73.33 $(59.21)^{cd}$
Chlorpyriphos (20 EC) @ 6.00 ml L^{-1}	60.00 $(50.76)^{bc}$	73.33 $(59.21)^{cd}$	100.00 $(88.71)^{a}$
Flubendiamide (39.35% SC) @ 0.20 ml L^{-1}	0.00 $(1.28)^{h}$	0.00 $(1.28)^{i}$	26.66 $(30.78)^{ij}$
Flubendiamide (39.35% SC) @ 0.30 ml L^{-1}	0.00 $(1.28)^{h}$	13.33 $(18.13)^{h}$	40.00 $(39.23)^{ghi}$
Flubendiamide (39.35% SC) @ 0.40 ml L^{-1}	0.00 $(1.28)^{h}$	40.00 $(39.23)^{efg}$	60.00 $(51.14)^{def}$
Chlorantraliniprole (18.5SC) @ 0.20 ml L^{-1}	0.00 $(1.28)^{h}$	0.00 $(1.28)^{i}$	20.00 $(26.56)^{j}$
Chlorantraliniprole (18.5SC) @ 0.40 ml L^{-1}	0.00 $(1.28)^{h}$	20.00 $(26.56)^{gh}$	33.33 $(35.00)^{hij}$
Chlorantraliniprole (18.5SC) @ 0.60 ml L^{-1}	0.00 $(1.28)^{h}$	33.33 $(35.00)^{fg}$	46.66 $(43.07)^{fgh}$
Metaldehyde @ 2.00 g m^{-2}	0.00 $(1.28)^{h}$	13.33 $(18.13)^{h}$	20.00 $(26.56)^{j}$
Metaldehyde @ 4.00 g m^{-2}	26.66 $(26.58)^{fg}$	66.66 $(55.36)^{cde}$	80.00 $(63.43)^{bc}$

Metaldehyde @ 6.00 g m^{-2}	60 $(51.14)^{bc}$	73.33 $(29.21)^{cd}$	100.00 $(88.71)^{a}$
Copper sulphate @ 1.00 %	40.00 $(39.23)^{cde}$	53.33 $(46.92)^{def}$	66.66 $(54.99)^{cde}$
Copper sulphate @ 3.00 %	66.66 $(54.99)^{b}$	93.33 $(80.29)^{ab}$	100.00 $(88.71)^{a}$
Copper sulphate @ 5.00 %	93.33 $(80.29)^{a}$	100.00 $(88.71)^{a}$	100.00 $(88.71)^{a}$
Control	0.00 $(1.28)^{h}$	0.00 $(1.28)^{j}$	0.00 $(1.28)^{k}$
CD (0.05)	(12.548)	(16.683)	(9.358)

Figures in parentheses are arc sin transformed. Mean of three replications.

Values with different letters are significantly different from each other by DMRT at 5 % level

4.3.3.2 Per cent mortality of GAS at forty-eight HAT

Copper sulphate 5 % recorded 100 per cent mortality of GAS and it was found statistically on par to the results of the treatments *viz.* copper sulphate3 % (93.33), carbosulfan @ 3 ml L^{-1}(93.33) and spinosad @ 0.90 ml L^{-1}(93.33) followed by spinosad@ 0.60 ml $L^{-1}$with 80.00 per cent mortality. Percentage mortality of 73.33 was recorded by the application of chlorpyriphos 6 ml $L^{-1}$and metaldehyde 6 g m^{-2}. As the exposure time increased from twenty-four to forty eight hours, the per cent mortality obtained by the application of flubendiamide (39.35% SC) 0.30 ml $L^{-1}$and 0.40 ml L^{-1} increased to 13.33 and 40.00 per cent respectively. A similar trend was obtained by the application of chemicals *viz.* flubendiamide (39.35% SC) 0.20 ml L^{-1}at 0.30 ml L^{-1} (20.00), 0.40 ml L^{-1} (33.33) and metaldehyde 2 g m^{-2}(13.33). However, the treatments such as flubendiamide (39.35% SC) 0.20 ml L-1 and chlorantraniliprole (18.5 SC) 0.20 ml L^{-1} were ineffective in causing mortality of GAS. The treatments *viz.*thiamethoxam (25 WG) 0.20 ml L^{-1}, flubendiamide at 0.30 ml L^{-1}, 0.40 ml L^{-1}, chlorantraniliprole 0.20 ml L^{-1} and metaldehyde 2 gm^{-2} were non-significant to control.

4.3.3.2 Per cent mortality of GAS at seventy-two HAT

In contrast to the scenario at twenty-four and forty eight HAT, 100 per cent mortality was recorded in eight treatments *viz.*,spinosad @ 0.60 ml $L^{-1}$and ml L^{-1}, carbosulfanat 2 and 3ml L^{-1}, copper sulphate at 3 and 5 %, chlorpyriphos 6 ml $L^{-1}$and metaldehyde 6 g/m^2. Carbosulfan at its lowest concentration (1 %) recorded 86.66 per cent mortality which was statistically on par with the highest concentration of thiamethoxam (0.60 ml L^{-1}) and metaldehyde 4 g m^{-2} with 80.00 per cent mortality followed by chlorpyriphos 4 ml L^{-1} (73.33). Flubendiamide @ 0.30 and 0.40 ml L^{-1}showed 46.66 and 60.00 per cent mortality of GAS and these treatments were statistically on par with each other.

Statistically significant variation was observed among mortality exhibited by thiamethoxam @ 0.20 ml L^{-1}(26.66) and 0.40 ml L^{-1}(53.33). However, chlorantraniliprole @ 0.40 ml L^{-1} and 0.60 ml L^{-1} exhibited per cent mortality of 33.33 and 46.66 respectively. Whereas, the lowest mortality of GAS *i.e*, 20.00 per cent was recorded by the application of chlorantraniliprole 0.20 ml L^{-1} and metaldehyde 2 g m^{-2}.

4.4 EVALUATION OF BOTANICALS AGAINST GIANT AFRICAN SNAIL

4.4.1 Evaluation of mortality

Leaf extracts of four plants and seed extract of one plant was treated against GAS to verify the mortality effect. The experiment revealed that, the botanicals evaluated against GAS was ineffective to cause mortality at 24, 48 and 72 HAT.

4.4.2 Evaluation of ovicidal effect

Leaf extracts of four plants and seed extract of one plant was treated to evaluate the ovicidal effect of GAS eggs. However, the botanicals were ineffective to cause ovicidal action at 24, 48 and 72 HAT.

4.4.3 Evaluation of antifeedant effect

4.4.3.1 Per cent leaf area protection at two HAT

A. indica seed extract @ 15 % showed the highest leaf area protection of 21.48 per cent and was significantly superior to all other treatments followed by *A. squamosa* seed extract @ 15 % concentration (16.57) and leaf extract of *L. camara* @ 25 % (9.95). The per cent leaf area protection exhibited by *A. indica* seed extract @ 8 % (2.63) was statistically on par with its lower concentration of 4 % (2.03). The effect of seed extracts of *A. indica* (2.63) and *A. squamosa* @ 8 % (1.53) concentration were statistically on par with each other.

Table 8. Antifeedant effect of different botanicals against GAS

Treatments	Percentage leaf area protection			
	2 HAT	4 HAT	6 HAT	8 HAT
Seed extract of *A. squamosa* @ 2 %	0.68 $(0.82)^{g}$	0.67 $(0.81)^{f}$	1.10 $(0.84)^{e}$	0.87 $(0.77)^{g}$
Seed extract of *A. squamosa* @ 4 %	1.13 $(1.05)^{efg}$	1.03 $(1.01)^{ef}$	1.15 $(1.24)^{de}$	1.18 $(1.08)^{efg}$
Seed extract of *A. squamosa* @ 8 %	1.53 $(1.22)^{def}$	1.53 $(1.22)^{def}$	1.26 $(1.30)^{de}$	1.33 $(1.28)^{ef}$
Seed extract of *A. squamosa* @ 15 %	16.57 $(4.06)^{b}$	13.30 $(3.61)^{b}$	15.52 $(3.98)^{b}$	13.66 $(3.69)^{b}$
Seed extract of *A. indica* @ 4 %	2.03 $(1.37)^{de}$	1.86 $(1.38)^{def}$	1.33 $(1.28)^{de}$	1.26 $(1.10)^{efg}$
Seed extract of *A. indica* @ 8 %	2.63 $(1.61)^{d}$	2.67 $(1.62)^{d}$	2.68 $(1.67)^{d}$	2.15 $(1.46)^{d}$
Seed extract of *A. indica* @ 15 %	21.48 $(4.62)^{a}$	20.59 $(4.51)^{a}$	23.38 $(4.87)^{a}$	18.95 $(4.34)^{a}$
Leaf extract of *L. camara* 10 %	0.76 $(0.85)^{fg}$	1.50 $(1.20)^{def}$	0.86 $(1.16)^{de}$	0.69 $(0.82)^{fg}$
Leaf extract of *L. camara* 15 %	1.76 $(1.32)^{de}$	2.29 $(1.51)^{de}$	2.04 $(1.59)^{de}$	1.79 $(1.33)^{de}$
Leaf extract of *L. camara* 25 %	9.95 $(3.15)^{c}$	8.73 $(2.93)^{c}$	9.42 $(3.14)^{c}$	8.59 $(2.92)^{c}$
CD (0.05)	(0.390)	(0.557)	(0.534)	(0.300)

Figures in parentheses are $\sqrt{X+1}$ transformed. Mean of three replications.

Values with different letters are significantly different from each other by DMRT at 5 % level

The antifeedant action exhibited by the leaf extracts of *L. camara* at 15 (1.76) and 10 % (0.76) concentrations were statistically significant with each other. The feeding inhibition exhibited by seed extract of *A. squamosa* @ 8 % found statistically on par to five other treatments *viz. A. indica* seed extracts at 8 and 4 % concentration, *A. squamosa* seed extracts at 4 % concentration and *L. camara* leaf extracts at 15 and 10 % concentrations. The lowest leaf area protection (0.68 %) was recorded by the application of *A. squamosa* seed extract @ 2 % and was statistically on par with *L. camara* leaf extract @ 10 % (0.76 %) (Table 8).

4.4.3.2 Per cent leaf area protection at four HAT

The highest per cent leaf area protection was recorded by the application of seed extract *A. Indica* @ 15 % (20.59) and was significantly superior to other treatments followed by *A. squamosa* seed extract @ 15 %(13.30) and *L. camara* leaf extract @ 25 % (8.73). The mean leaf area protection exhibited by the application of seed extracts of *A. indica* @ 4 %(1.86) and 8 % (2.67) concentration were statistically on par with each other. The lowest per cent leaf area protection was exhibited by the application of *A. squamosa* seed extract @ 2 % (0.67) and it was found statistically on par with *A. squamosa* seed extracts @ 8 %(1.03) and 4 % (1.53), *L. camara* leaf extract @ 10 % (1.50) and *A. indica* seed extract @ 4 % (1.86).

4.4.3.3 Per cent leaf area protection at six HAT

The mean leaf protection of 23.38 per cent was recorded by the application of *A. indica* seed extract @ 15 % and was statistically significant to other treatments. It was followed by *A. squamosa* seed extract @ 15 % and *L. camara* leaf extract @ 25 % with 15.52 and 9.42 per cent mean leaf area protection respectively. The per cent leaf area protection exhibited by *A. indica* seed extracts @ 4 % (1.33) and 8 % (2.68), *L. camara* leaf extracts @ 10 % (1.16) and *A. squamosa* seed extracts @ 2 % (1.10), 4 % (1.15) and 8 % (1.26). The lowest per cent leaf area protection was exhibited by *A. squamosa* seed extracts @ 2 % (1.10).

4.4.3.4 Per cent leaf area protection at eight HAT

The mean leaf area protection exhibited by the application of *A. indica* seed extract @ 15 % was 18.95 per cent and was statistically significant to others followed by *A.squamosa* seed extract @ 15 % (13.66) and *L. camara* leaf extract @ 25 % (8.59). The per cent leaf area protection obtained by the application of *A.indica* seed extract @ 8 % (2.15) and *L. camara* leaf extract @ 15 % (1.79) were on par with each other. The lowest leaf area protection (0.69) was recorded from *L. camara* leaf extract @ 10 % and it was statistically on par with *A. squamosa* seed extracts @ 2 % (0.87) and 4 % (1.18) and *A. indica* seed extract @ 4 % (1.26).

4.5 EVALUATION OF PATHOGENIC NEMATODES AGAINST GIANT AFRICAN SNAIL

Pathogenic nematodes *viz. Heterorhabditis bacteriophora*, *H. indica*, *Steinernema abbasi, S. bicornutum*, *S. carpocapsae* and *Rhabditis* sp. were treated against GAS. The results revealed that the pathogenic nematodes were unable to cause mortality at 24, 48 and 72 HAT.

4.6 EVALUATION OF ENTOMOPATHOENIC FUNGI AGAINST GIANT AFRICAN SNAIL

The entomopathogenic fungi *viz. Metarhizium anisopliae*, *Beauveria bassiana* and *Lecanicillium lecanii* were ineffective in causing mortality of GAS even at two weeks after treatment.

Discussion

5. DISCUSSION

Giant African snail, *Achatina fulica*, was considered as the largest as well as notorious terrestrial mollusc and was known to cause important economic damage to cultivated crops (Mayer and picot, 2001). The GAS was reported to feed on different parts of plants irrespective of their age. They were found feeding on leaves, barks, stems, buds, flowers and fruits. Major reasons for any species to become pestiferous in its introduced range is lack of natural enemies in human modified landscapes and its intrinsic adaptability (Lelwala *et al.*, 2010). Being a voracious herbivore, the species become a severe agricultural pest and also out-compete with the indigenous mollus species (Raut and Barker, 2002).

5.1 DISTRIBUTION OF GIANT AFRICAN SNAIL AND ITS NATURAL ENEMIES

5.1.1 Distribution of giant African snail

A survey was conducted in selected five hot spots of ten panchayats in Thiruvananthapuram district (Plate 6). The survey recorded, the highest number of adult GAS from Pulimath panchayat and that of juveniles from Vakkom panchayat respectively. The lowest population of both adults and juveniles were reported from Tholikkodu panchayat (Fig. 1). The juvenile and adults of GAS were identified based on the number of whorls, length and breadth of its shell. In the case of juvenile snails (less than six months old), the number of whorls were less than six and the length and breadth of the shell were less than 60.34 mm and 29.8 mm respectively (Ghose, 1959; Ravikumara *et al.*, 2011) (Plate 7). The variation in snail population may be due to the microclimatic condition in those surroundings surveyed. The highest population of snails from Pulimath panchayath may be as a result of rubber and other trees providing shade as well as the litter fall from these trees might have provided a hiding place for the snails. Moreover, the presence of Vamanapuram river and its streams might have provided moist condition for better establishment of snail population. However, in Vakkom panchayath also the canopy of the vegetation was conducive for the

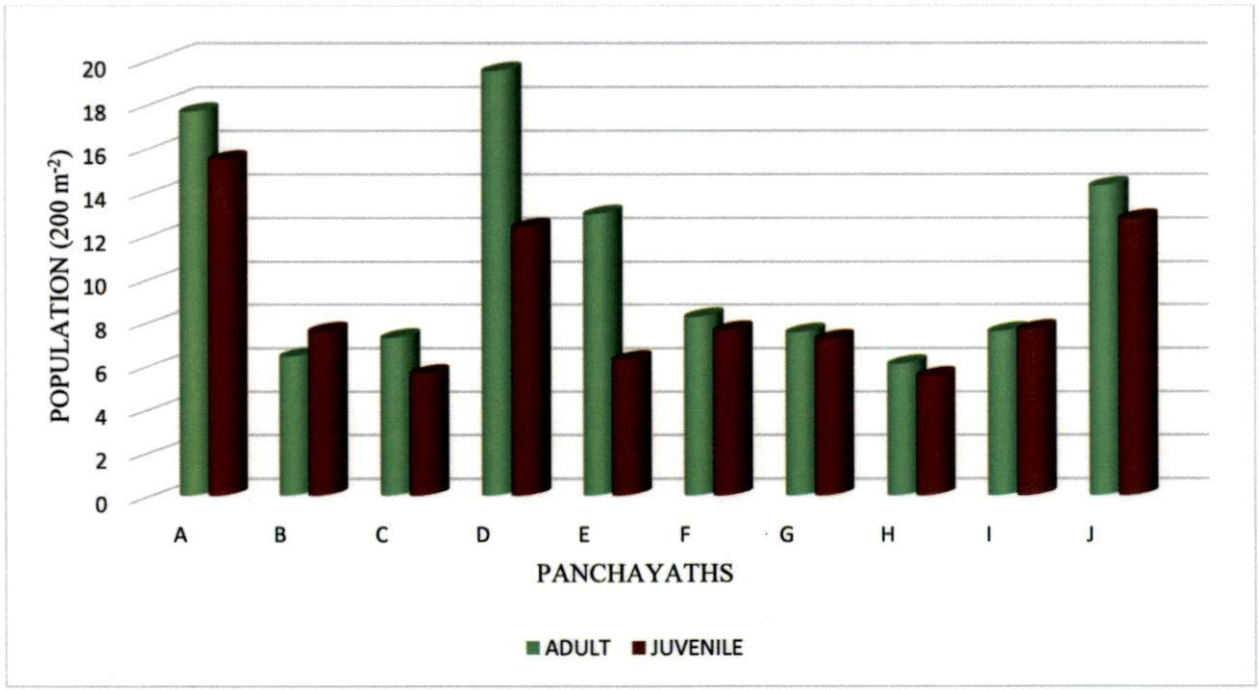
a) Mud pots used for the survey

b) placement of pots carrying fermented bait

c) Snails trapped

d) Snails trapped

Plate 6. Mud pot trap used during survey



A) VAKKOM
B) CHIRAYINKEEZHU
C) KADAKKAVOOR
D) PULIMATH
E) KILIMANOOR
F) NAGAROOR
G) PAZHAYAKUNNUMMEL
H) THOLIKKODU
I) VITHURA
J) VELLARADA

Figure 1. Distribution of giant African snail in Trivandrum district

Plate 7. Adults and juveniles of *A. fulica*

establishment of snail population. The cropping situation was almost the same for all panchayaths, except, the presence of rubber plantaions in some localities (Plate 8). The difference in population may be due to the peculiarities in population dynamics of GAS as explained by Mead, (1961); (1979a); Pointier and Blanc, (1985); Raut and Barker, (2002). They explained that the population of GAS were subjected to pass through three different phases, a phase of exponential increase, with the population of large, vigorous individuals, a stable phase of variable duration and a phase of decline, with the population characterized by small individuals.

5.1.2 Natural enemies

Among the invertebrates, flat headed worm (*Bipalium* sp.), grub of firefly and red ant (*Oecophylla smaragdina*) were recorded as natural enemies of GAS. Whereas, among vertebates, crow pheasant (*Centropus sinensis*), tree pie (*Dendrocitta vagabunda*) and house rat, (*Rattus rattus*) were recorded as natural enemies of GAS (Plate 9).

The *Bipalium* sp. recorded from the present study was found feeding on juveniles of GAS (less than 30.00 mm length) by secreting a digestive fluid to its flesh. Such extra oral digestion of snail was reported by Raut and Ghose, (1979a). The role of *Bipalium* sp as a predator of GAS was not significant due to imbalanced predator-prey population, the predator being much less in number (Raut and Ghose, 1979a).

The fire fly grub was found feeding on the flesh near the columellar region of GAS. Similar observations were obtained by Mead (1961), who found the fire fly grub feeding on the flesh near the base of columella with the help of its strong mandibles.

The red ant, *O. smaragdina* were found aggregating near GAS. Observation on carrying the early juveniles of GAS was also recorded. similar observations were recorded by Raut and Ghose (1984). Who also found that the victims were those snails which were either late to return to their hiding places or were weakened by heavy sun

a) Hibiscus

b) Bread fruit

c) Banana fruit bunch

d) Elephant foot yam

e) Banana pseudostem

Plate 8. Attack of *A fulica* on various plants

a) Flat headed worm

b) Crow pheasant

Plate 9. Natural enemies of GAS

light. Mead (1961) observed that the ants were unable to kill the snails and they found aggregated near dead or dying snails.

The crow pheasant, *C. sinensis* and tree pie, *D. vagabunda* were identified as the avian natural enemies of GAS. It was in accordance with the results of many other workers such as Rees (1951); Williams (1953); Raut and Ghose (1979b). The attacked GAS shells were having characteristic diamond or triangle shaped wounds due to bird pecks. This was in accordance with the observations of Williams, (1953). Since the snails are nocturnal in habit, the birds are not very effective in reducing their population (Raut and Ghose, 1979b). *R. rattus* was recorded as a mammalian natural enemy of GAS. They were found feeding on juveniles and adults of snails. A similar observation was recorded by Allen (2002), who found *Rattus* sp. feeding on GAS. Limm (1966); Baldwin and Casey (1983); Allen (2002) observed that the mammalian predators were adopting various methods to feed on GAS such as, direct feeding, biting off the shell spire, breaking through the side of the shell, or by gnawing pieces of the shell. Potts (1975) reported 74 per cent reduction in population of *Cantareus asperses,*(terrestrial snail) by *R. rattus* .

5.1.3 Other snails and slugs

Four species of snails were observed during the study. Two belonged to the genus Macrochlamys, and others belonged to genus Opeas (*O. gracile*) and Ariophanta (*A. bistrialis*) respectively. *Macrochlamys* sp. and *A. bistrialis* belonged to the same family, Ariophantidae, but differed in subfamily level (Macrochlamydinae and Ariophantidinae). Whereas, *O. gracile* belonged to the family Subulinidae (Mitra *et al.*, 2005). The *O. gracille* were observed from potted plants and fallen leaves of college garden. They were feeding and hiding behind the leaves. Similar investigations were observed by Roy and Mukherjee (1969). They observed *O. gracile* feeding on freshly fallen or slightly decomposed littered leaves of *Clitoria ternatea, Nerium indicum, Ixora* sp., *Coccinea* sp., *Dolichos lablab* and *Capsicum* sp.

Macrochlamys sp. was found feeding on garden plants such as marigold, zinnia, elephant foot yam, amaranthus, cabbage and cauliflower and they were found defoliating the lamina leaving the midribs intact. Similar observations were recorded by Raut and Ghose (1984). They found *Macrochlamys* sp. was feeding from leaves of cucurbits, gourds, beans, lettuce, luffa, cabbage, cauliflower, amaranth, castor, chrysanthemum, marigold, clitoria, pothos, drum stick, pedilanthus and cosmos. They also observed the snail feeding on the leaf lamina leaving the midrib intact.

A. bistrialis was found feeding on the tender portions of the stem and also on leaves of various plants. The same species was also observed feeding on pseudostem by scraping its tissues and rasping on leaves of banana. This was in accordance with the observations of Raut and Ghose (1984). They observed that, the snail *Ariophanta solata*, feeding on leaves and stems of *Coffea arabica* and *Erythrina lithosperma*. The rasped stem portions were found to break off at the point of attack when, exposed to strong winds (Subba Rao, 1975).

Two species of slugs were also observed during the study. They were, *Mariella dussumieri* and *Laevicaulis alte.* The *M. dussumieri* belonged to family Ariophantidae and *L. alte* to Veronicellidae (Naik *et al.*, 2014; Molet, 2014). The slugs were found attacking seedlings of marigold, cowpea, amaranthus, cabbage and cauliflower and defoliating mature plants of portulaca, cabbage, orchids, anthurium and banana. They were found hiding inside the leaf axils of banana and rasping on the soft tissues. Orchids, cabbage and cauliflower were reported as host plants of *L. altae* by Raut (1999). Daniel and Vanavasan (2009) observed hibiscus, cocoa, banana and anthurium as the host plants of slugs. Slugs found feeding on buds, flowers, growing shoot tips and foliage of marigold was recorded by Naik *et al.* (2014) (Plate 10).

a) Ariophanta bistrialis

b) *Opeas gracillae*

c) *Macrochlamys* sp.

d) *Mariella dussumieri*

e) Laevicaulis altae

Plate 10. Other snails and slugs observed

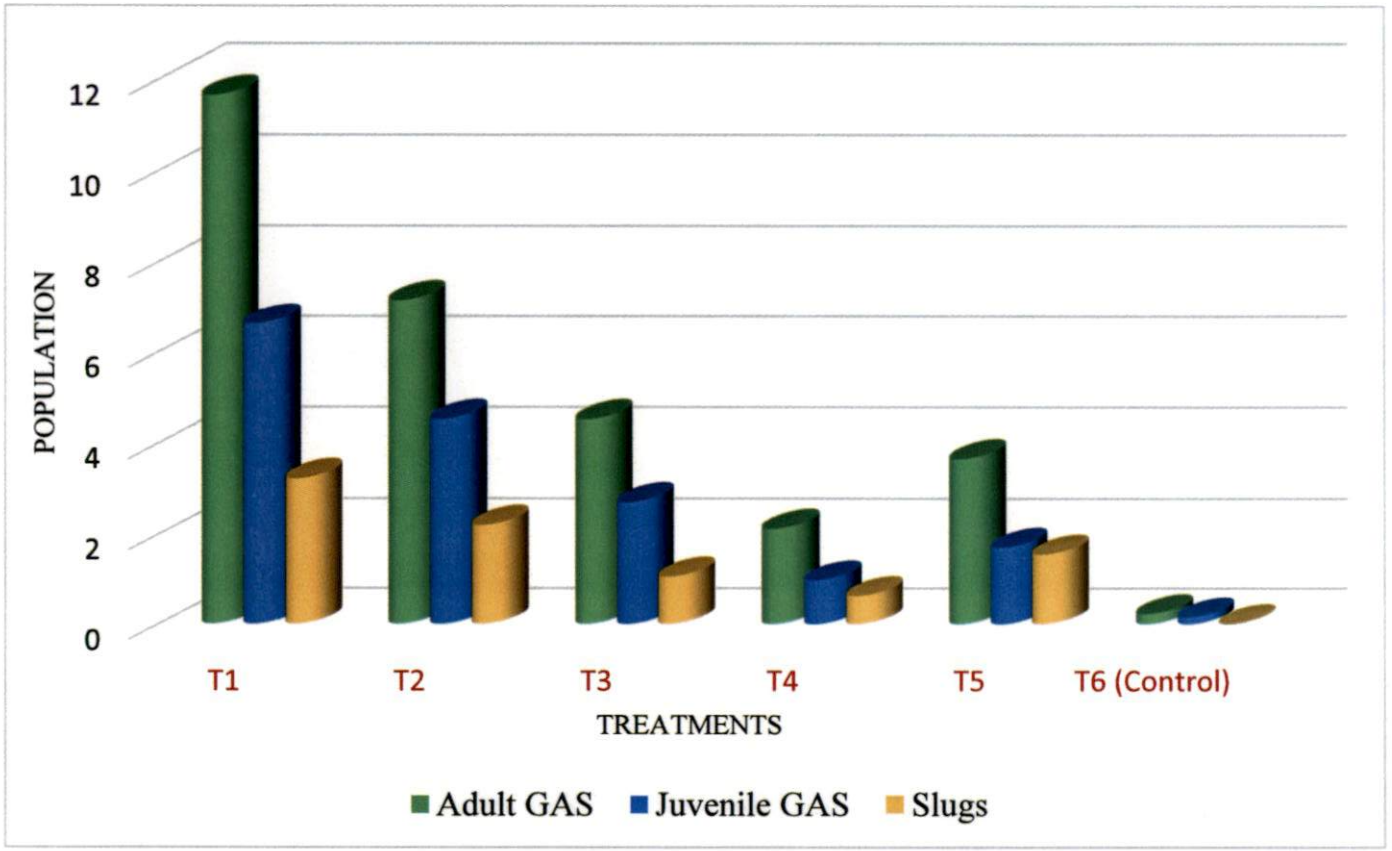
5.2 EVALUATION OF DIFFERENT BAITS AND TRAPS AGAINST GAS

5.2.1 Evaluation of different baits

Among the baits evaluated, pappaya leaf pulp + jaggery + wheat flour (T1) was found to be the best bait for snails and slugs followed by the treatment, pappaya leaf pulp + jaggery + cooked rice (T2) (Fig. 2). Attraction of GAS towards fermented products was observed by Vanitha *et al.* (2008); Shevale and Bedse (2009). The presence of jaggery as a source of sugar and wheat flour or cooked rice as a source of carbohydrate resulted in fermentation of bait. From the preliminary observations, the papaya was identified as a preferred host plant for the GAS and it consumed papaya leaves, stems, flowers, buds immature and mature fruits. This was previously observed by, Thakur (1999); Sridhar *et al.* (2012). They observed malformations in floral characters, scrapings on stem and fruits due to snail attack. Basavaraju *et al.* (2001); Shevale and Bedse (2009) observed that, more number of snails were attracted to fermented poison baits containing wheat bran or rice bran, jaggery and yeast along with pesticide. Instead of rice bran, wheat flour was used during present study and no chemical was used. The ingredients for T1 and T2 were almost the same, except the use of wheat flour in T1 instead of cooked rice in T2. So, the chances for quick fermentation was more in T1 due to the presence of fine wheat flour instead of coarse cooked rice in T2 (Plate 11). The scenario was different for the treatments including papaya leaf pulp and banana leaf pulp. Among which the GAS exhibited a preference to papaya leaf pulp, this was in agreement with the findings of Thakur (1999); Ravikumara *et al.* (2007). They found that, papaya based baits attracted more number of snails compared to other baits.

5.2.2 Evaluation of traps against GAS

Among the traps evaluated, T5 [wet jute sac with papaya leaves (750 g)] and T1 [Wet jute sac with fermented bait and poison (500 g wheat + 200 g jaggerry + 5 g yeast, copper sulphate 6 %)] showed significantly higher number of snails trapped



T1 : Papaya leaf pulp * **T2** : Papaya leaf pulp # **T3** : Banana leaf pulp * **T4** : Banana leaf pulp #

T5 : Bread (100g) + jaggery (50g) **T6** : Control (wet jute sac alone)

 # - (0.5kg) +jaggery (100g) + cooked rice (0.5kg) ***** - (0.5kg) + jaggery (100g) + wheat flour (0.5kg)

Figure 2. Snails and slugs attracted to different treatments

T1

T2

T3

T5

T1: Papaya leaf pulp * **T2**: Papaya leaf pulp # **T3**: Banana leaf pulp * **T5**: Bread (100g) + jaggery (50g)

- (0.5kg) +jaggery (100g) + cooked rice (0.5kg) * - (0.5kg) + jaggery (100g) + wheat flour (0.5kg)

Plate 11. Evaluation of different baits for giant African snail

followed by T2 [Mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)] after first day of exposure of traps to snails. Whereas after second day of exposure, T2 and T1 showed highest number of snails trapped followed by T5. On third day of exposure the treatment T2 was statistically superior in trapping the snails when compared to other treatments. Hence, T2 was considered as the best trap against GAS. The reason for difference in number of snails trapped may be attributed to the structure and shape of traps used. In T2 the bait was applied in mud pot with curved walls. Hence, the chances of escape from the trap by the snail might be minimal. The other reason for attracting more snails in the mud pot trap can be attributed to its efficacy to retain moisture and creating an ambient condition for attracting snails. The chances of escape of snails were more in T1 and T5 since the bait was applied in jute sac placed in a pit. Since walls of the trap were devoid of any curvature it might be easy for snails to climb up and escape. The number of GAS trapped in T3[Plastic bottle (30 cm height and 10 cm diameter) with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %)] was found lesser, it might be due to the inability of plastic to retain moisture. Since the walls of pit trap was rugged, the snails might have escaped easily (Plate 12). Hence it was found less effective. According to Mead (1961), even though the bait technique was effective in killing snails, if they were less cost effective, created threats to other animals and difficult to prepare. Hence, the trap should be devoid of those difficulties. From the present study, T2 was identified as the best trap. The advantages of mud pot trap over other traps are: its eco friendliness, cost effectiveness, reusability, and its effectiveness to create less hindrance to non-target organisms including domestic animals. It was less prone to damage by wandering animals.

T1

T2

T5

T4

T3

T1 : Wet jute sac with fermented bait and poison # **T2 :** Mud pot with fermented bait and poison #**T3 :** Plastic bottle (30 cm height and 10 cm diameter) with fermented bait and poison #**T4 :** Pit with fermented bait and poison #**T5 :** Wet jute sac with papaya leaves (750 g)# -(500 g wheat + 200 g jaggery + 5 g yeast , copper sulphate 6 %)

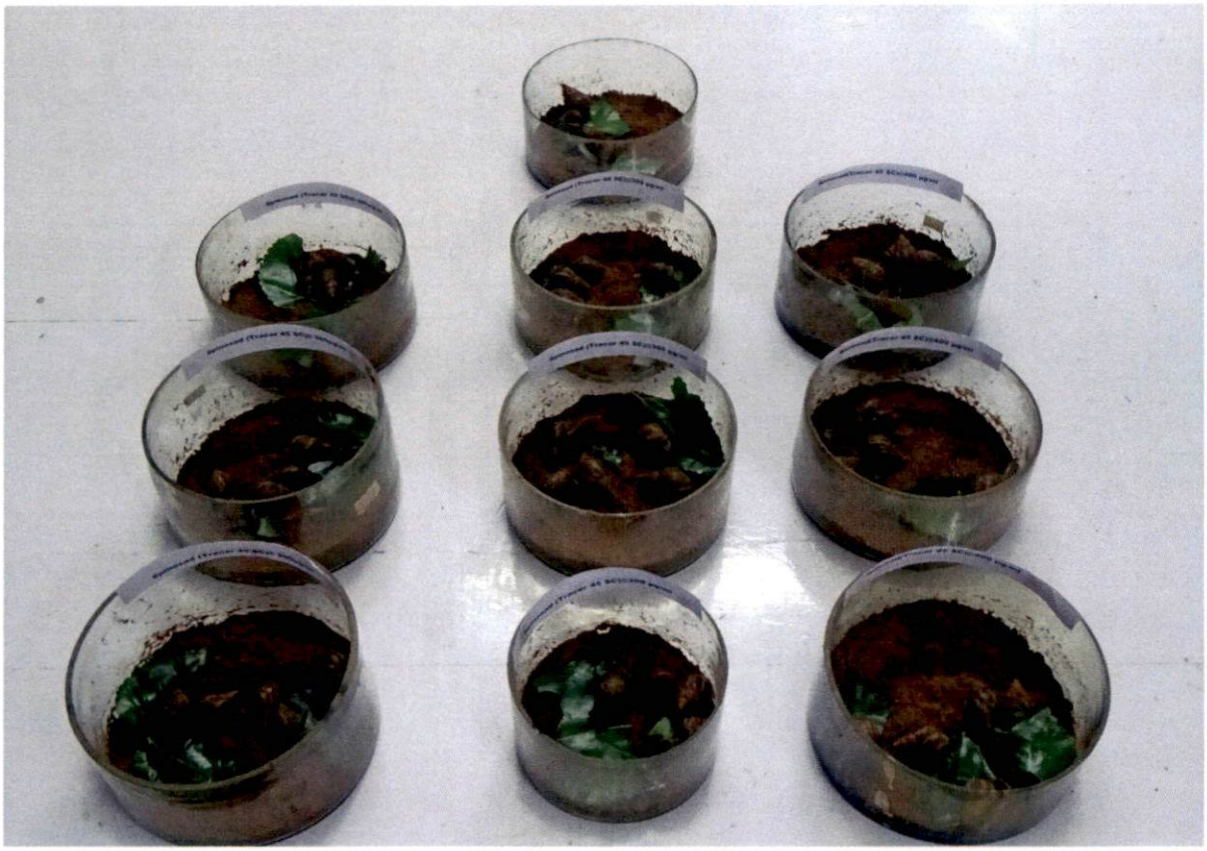
Plate 12. Evaluation of various traps

5.3 EVALUATION OF CHEMICALS AGAINST GIANT AFRICAN SNAIL

5.3.1 Evaluation of mortality

Five among the eight chemicals evaluated, were effective in causing mortality of GAS at different intervals of exposure (Plate 13). At twenty-four HAT, highest mortality of GAS was recorded by the application of copper sulphate 5 % followed by copper hydroxide 4 %. At forty-eight hours after exposure, the copper sulphate 5 % exhibited the highest mortality and it was found statistically on par with that exhibited by the application of copper hydroxide 4 % and copper oxychloride 4 %. Copper sulphate 5 % was the only chemical that showed a statistically significant mortality over others at seventy-two HAT. Kakoty and Das (1988) recorded 98 per cent mortality of GAS by the application of copper sulphate. Thakur (1999) observed 100 per cent mortality of snails after the application of copper sulphate and she recommended 10 % strength of this chemical against *A. fulica* in field conditions. However, the results of the present study showed that copper sulphate at 5 % strength was effective to cause 93.33 per cent mortality of the snails up on exposure to seventy-two HAT in laboratory condition. Excess mucous secretion was observed from the dead *snails*, followed by desiccation and death. According to Blasco and Puppo (1999); Snyman *et al.* (2005), molluscicidal activity of copper based products were due to the accumulation of copper in the digestive glands of snails. Gould *et al.* (1988); Snyman *et al.* (2004) observed that the reproductive tract of molluscs were also a target site for metals like copper. The accumulation of copper may lead to the excessive secretion of mucous and finally the death of organisms.

Application of sodium chloride @ 10 % exhibited 33.33 per cent mortality of GAS after twenty-four, forty-eight and seventy-two hours of exposure. Raut and Ghose (1984) reported the use of common salt in Eastern India to kill GAS. Shah (1992) reported that the application of common salt reduces snail population. Whereas in a



a) GAS treated with chemical

b) Effect of copper sulphate 5%
at 72 HAT

c) Effect of copper hydroxide 4%
72 HAT

Plate 13. Mortality effect of chemicals againt GAS

study conducted to manage GAS by Saxena and Dubey (1970) revealed that the application of common salt (as dust) resulted in complete burning of foliage.

5.3.2 Ovicidal action

The chemicals evaluated were ineffective in causing mortality of GAS (Plate 14). This was in contrast to the findings of Iglesias *et al.* (2002). They found that Methiocarb @ 7.86×10^{-1}mg ai cm^{-2} was an effective chemical in causing ovicidal action of slug, *Deroceras reticulatum* Muller. The ovicidal action exhibited by metaldehyde @ 1.18 mg ai cm^{-2} was lesser than that of methiocarb.

5.3.3 Evaluation of chemicals as poison baits

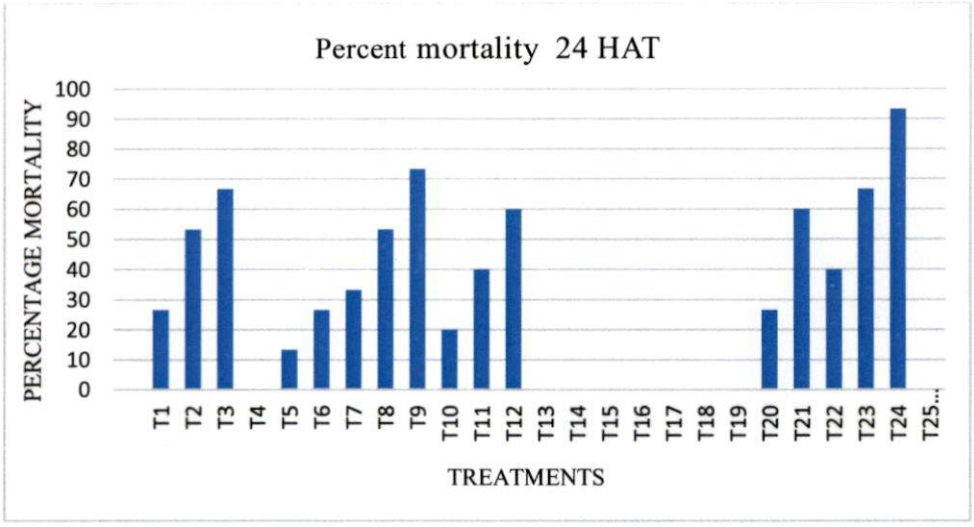
Among the eight chemicals evaluated as poison baits in the laboratory, copper sulphate 5 % exhibited highest per cent mortality after twenty-four HAT, followed by copper sulphate 3 % and spinosad 45 SC @ 0.90 ml L^{-1}. Whereas at forty-eight HAT, copper sulphate 5 % recorded 100 per cent mortality followed by copper sulphate 3 %, spinosad 45 SC @ 0.90 ml L^{-1} and carbosulfan 25 EC @ 3 ml L^{-1} (Plate 14). However, at seventy-two HAT, five chemicals *viz.* spinosad @ 0.60 ml L^{-1} and 0.90 ml L^{-1}, carbosulfan @ 2 and 3 ml L^{-1}, copper sulphate @ 3 and 5 %, chlorpyriphos @ 6 ml L^{-1} and metaldehyde 6 g m^{-2} exhibited 100 per cent mortality of snails (Fig. 3).

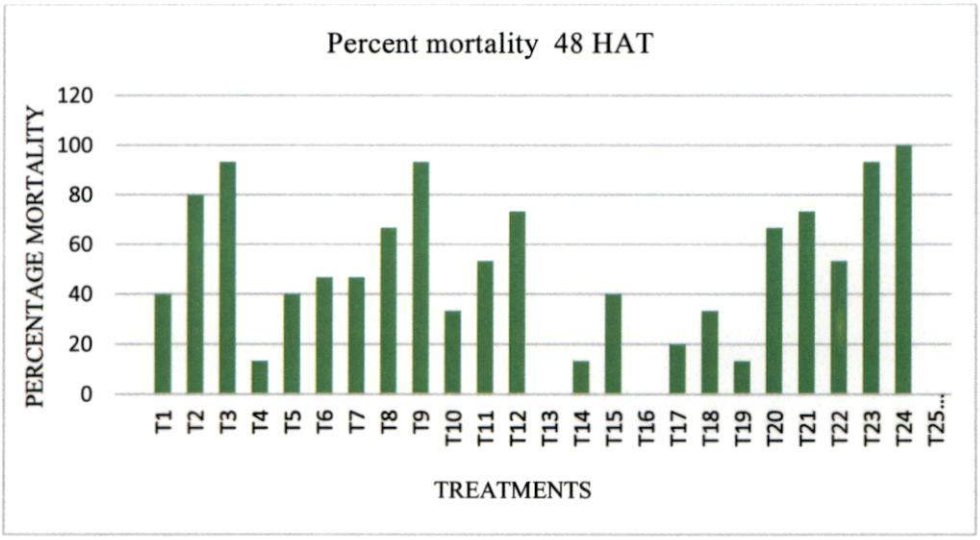
Copper sulphate 5 % was the only chemical which showed highest mortality of GAS at twenty-four, forty-eight and seventy-two HAT followed by copper sulphate 3 % when applied along with food bait. Profuse mucous secretion was observed from the dead snails. Ninety-five per cent mortality of snails were obtained by the application of copper sulphate dust (40%) (Bharadwaj, 1972). Saxena and Dubey (1977) used powdered copper sulphate @ 5.5 kg/ha and they obtained mortality of snails as 93 per cent. Whereas, Kakoty and Das (1988) observed a 100 per cent mortality of GAS in field condition after the application of copper sulphate. Blasco and Puppo (1999); Snyman *et al.* (2005) reported that molluscicidal activity of copper was primarily due to the accumulation of copper in their digestive glands.

a) Treated eggs

b) Hatched eggs

Plate 14. Ovicidal effect of chemicals against GAS





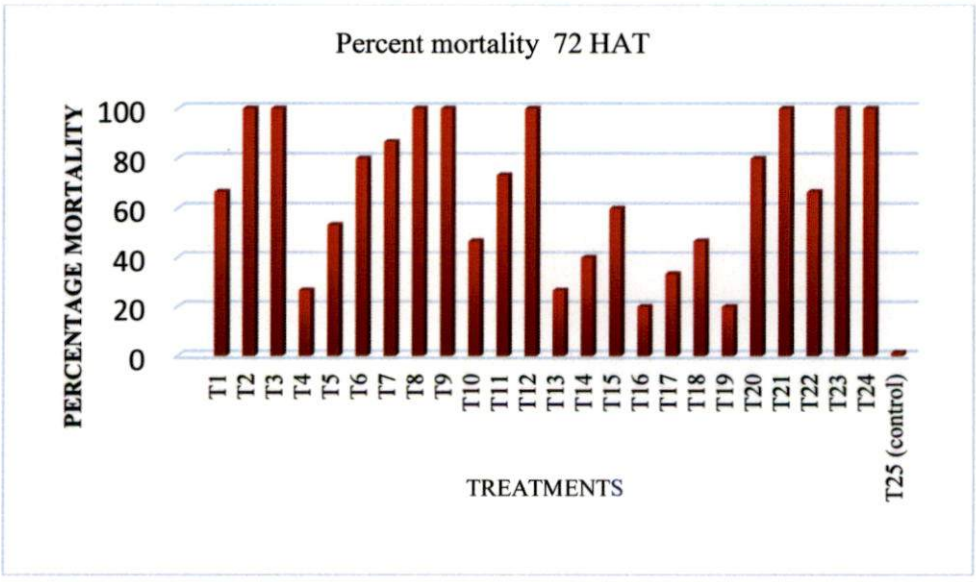


Figure 3. Effect of various chemicals as poison baits against giant African snail

100

Spinosad 45 SC @ 0.60 ml L^{-1} and 0.90 ml L^{-1} exhibited 100 per cent mortality of snails at seventy-two HAT. The snails exposed to spinosad were exhibited excessive mucous secretion. These findings were in accordance with that of Borth *et al.* (1996), they identified the LC_{50} value of spinosad against molluscs (Eastern oyster) as 0.295 mg L^{-1}, which was found lesser when compared with other invertebrates. Hence, they reported that marine molluscs were sensitive to spinosad.

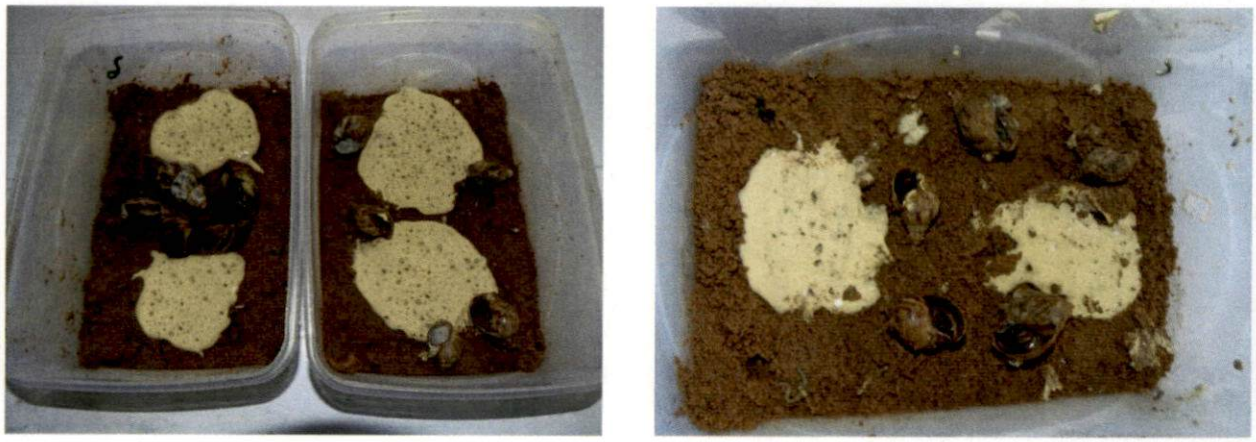
Carbosulfan 25 EC applied as poison bait @ 2.00 ml L^{-1} and 3.00 ml L^{-1} exhibited 100 per cent mortality at seventy-two HAT. Basavaraju *et al.* (2001) observed 100 per cent mortality of GAS by the application of carbofuran (600 g carbofuran 3G + 60 kg rice bran + 6 kg jaggery ha^{-1}) and methomyl (600 ml methomyl 40 SP + 60 kg rice bran + 6 kg jagery ha^{-1}) based baits. Shevale and Bedse (2009) found that application of methomyl 40 SP@10g kg^{-1} of fermented food bait (50 kg ha^{-1} wheat bran + 5 kg jaggery + yeast 30 g kg^{-1}) was effective in killing snails. The dead snails exhibited excessive mucous secretion and were unable to withdraw the body completely into the shell. This observation was in agreement with the findings of Shevale and Bedse (2009). Frain (1982) observed the interruption of neurotransmitter cholinesterase from the molluscan system after the application of carbamates. The application of carbamates caused rapid paralysis and loss of muscle tone in molluscs (Godan, 1983).

Chlorpyriphos 20 EC@ 6.00 ml L^{-1} when used as poison bait, expressed 100 per cent mortality of GAS. The present findings were in accordance with the results obtained by Basavaraju *et al.* (2001). They observed a 100 per cent mortality of GAS exposed to monocrotophos based bait (600 ml monocrotophos 36 SL + 60 kg rice bran + 6 kg jaggery ha^{-1}) under laboratory conditions. Panigrahi and Raut (1993) observed mortality of GAS when fed with dichlorovos injected vegetables (*Solanum lycopersicum*, *Trichosanthes dioica*). Justin *et al.* (2008) found reduction in population of GAS, after application of phorate 5G @ 5 g $vine^{-1}$ in vanilla plantation.

Metaldehyde pellets when applied at the rate of 6.00 g m^{-2} resulted in 100 per cent mortality in the laboratory. Metaldehyde, as a molluscicide was extensively studied by many workers. Nair *et al.* (1968) reported 100 per cent mortality of GAS after the dust application of metaldehyde at 1-2 per cent strength. The combined application of 5 per cent metaldehyde and 20 per cent calcium arsenate resulted in 96.70 per cent mortality of snails (Srivastava, 1976). According to Thakur (1998), 100 per cent mortality of GAS was observed after seventy-two hours of exposure by the application of metaldehyde (2.5 per cent pellets) @ 20-25 kg ha^{-1}. Excess mucous secretion followed by dessication and inability of the snail to withdraw the body was recorded as the symptoms of metaldehyde toxicity in the present study and was in accordance with the findings of Thakur (1998); Javeregowda (2006); Shevale and Bedse (2009). Henderson and Triebskorn (2002) found that metaldehyde stimulated the mucous gland to secrete excess slime leading to desiccation and death of GAS (Plate 15).

Thiamethoxam 25 WG was another chemical which showed a significant mortality of snails. Application of thiamethoxam 25 WG @ 0.60 ml L^{-1}exhibited 80.00per cent mortality of GAS after seventy two hours of exposure. This finding was in accordance with that of Abog *et al.* (2012). They reported 38 per cent mortality of snails after the application of thiamethoxam @ 400 ppm.

From the present study, it was evident that chemicals belonging to diamide group *i.e*, flubendiamide 39.35% SC and chlorantraliniprole 18.5 SC at higher doses were able to exhibit mortality of GAS when applied as poison bait. At twenty-four HAT both the chemicals were unable to exhibit mortality but, at forty-eight HAT, flubendiamide @ 0.30 and 0.40 ml L and chlorantraniliprole @ 0.40 and 0.60 ml L were able to exhibit mortality of GAS. At seventy-two HAT, both the chemicals at all different concentration were able to show mortality. The symptoms of death were, inability to withdraw the body parts completely in to the body and excessive mucous secretion. Cordova *et al.* (2006); Bassi *et al.* (2009) discussed about the mode of action



a) Dead snails

b) Partial withdrawal of body into shell

Plate 15. Effect of various poison baits against GAS

of these group of chemicals in insect body. According to them, the chemicals leads to impaired muscle regulation, paralysis and death of sensitive species.

5.4 EVALUATION OF BOTANICALS AGAINST GAS

5.4.1 Mortality effect

Results of present study revealed that, the leaf extracts of *Piper nigrum*, *Solanum nigrum, Azadirachta indica, Clerodendron infortunatum* and seed extract of *Annona squamosa* were ineffective to cause mortality of GAS at 24, 48 and 72 HAT. Thakur (1998) observed that the leaf extracts obtained from black pepper was effective to cause molluscicidal action and which was in contrary to the present findings. Prasad *et al.* (2004) observed that the cuttings of *Annona glabra* can repel GAS from nursery. However, findings of the present study revealed the ineffectiveness of *A. squamosa* seed extract in causing molluscicidal action.

5.4.2 Ovicidal effect

The results of present study revealed that the botanicals evaluated were unable to cause ovicidal action against GAS. The results of the studies conducted by Rapado *et al.*, 2013 on *Biomphalaria glabrata,* a fresh water snail suggests that the ethanolic extract of *Piper tuberculatum* (both leaf and infloresence extract), *Piper crassinervium* (inflorescnce extract) and *Piper glabella* (leaf extract) were able to cause embryonic mortality of snails, which was in contrary to present findings.

5.4.3 Antifeedant effect

Application of the seed extract of *A. indica* @ 15 % showed a highest per cent leaf area protection to a tune of 21.48, 20.59, 23.38 and 18.95 at two, four, six and eight HAT respectively. The per cent leaf area protection exhibited by all other botanicals were less than that of *A. indica* seed extract @ 15 %. Jhansirani and Jaganmohan (1999) observed a feeding inhibition of 53.81% after twenty-four hours of exposure to 4 % neem seed kernel extract (NSKE) against GAS. Results of the experiment conducted

by Padro (1992) revealed that NSKE was effective in causing mortality of *Indoplanorbis exustus.* However, it was not effective against *Pomacea* sp.

Application of *A. squamosa* seed extract @ 15 % exhibited per cent leaf area protection to a tune of 21.48, 20.59, 23.38 and 18.95 at two, four, six and eight HAT respectively. This was in agreement with the findings of Jhansirani and Jaganmohan (1999), they recorded a feeding inhibition of 79.29 %, after twenty-four hours of exposure of GAS to 4 % *A. squamosa* seed kernel extract. The antifeedant action might be due to the presence of annonacin. The antifeedant and molluscicidal action of annonacin was reported by many workers (Gallardo *et al.,* 1998; Dos santos *et al.,* 2001 and Prasad *et al.,* 2004).

The per cent leaf area protection of 9.95, 8.73, 9.42 and 8.59 at two, four, six and eight HAT respectively were recorded by the application of leaf extract of *L. camara* @ 25 % against GAS. The molluscicidal action of *Lantana indica* was observed by Srivastava *et al.* (2007) on a fresh water snail, *Lymnea acuminiata.* They identified that, the LC_{50} of *L. indica* leaf extract for *L. acuminiata* was 111.27 mg L^{-1}. This result was in tune with present findings. The presence of chemical substances such as, lantadene, lantoniside, linaroside and carmarinic acid might be responsible for the biocidal properties exhibited by extracts of *L. camara* (Kulkarny *et al.,* 1997).

5.5 EVALUATION OF PATHOGENIC NEMATODES AGAINST GAS

Three pathogenic nematodes *viz. Heterorhabditis bacteriophora, H. indica, Steinernema abbasi, S.* bicornutum, *S. carpocapsae* and *Rhabditis* sp. were evaluated against GAS. None of them were effective to cause mortality of GAS. Similar observations were obtained by Williams and Rae (2015), they observed that the nematode species, *Phasmarhabditis hermaphrodita,* which was known for its molluscicidal activity was unable to cause mortality of GAS. They found nematodes were encapsulated and killed inside the shell of *A. fulica.*

5.6 EVALUATION OF ENTOMOPATHOGENIC FUNGI AGAINST GAS

The results of the study revealed that no entomopathogenic fungi, evaluated against GAS were able to cause mortality of snails. The spore attachment, germination, penetration and further establishment of the pathogenic fungi in to its body might have been inhibited by the profuse secretion of mucous by snails.

Summary

6. SUMMARY

The giant African snail *Achatina fulica*, is a highly invasive terrestrial snail native to East Africa. According to the global invasive species database, *A. fulica* is the second most invasive alien species in the world. It has now invaded most parts of the world with particular impact in tropical and subtropical regions (Lowe *et al.*, 2000). It was introduced to kolkata during 1847 and was believed that from there it got dispersed to different locations within the country. Plenty of investigations were conducted by various workers on different aspects of GAS both from India and abroad. However, limited publications were available pertaining to the management of GAS from kerala. In this context, a study entitled, "Management of giant African snail *Achatina fulica* (Bowdich)" was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani during 2014-2016.

As a part of the present study, a survey was conducted to delineate the distribution of GAS in Thiruvananthapuram district. Among the ten panchayaths surveyed, Pulimath and Vakkom panchayaths recorded the highest number of adults and juveniles of GAS respectively. Whereas, the lowest population was obtained from Tholikkodu panchayath for both adults and juveniles. Both invertebrates and vertebrates were recorded as natural enemies of GAS. Flat headed worm (*Bipalium* sp.), grub of firefly (*Oculogryphus pterotus*) and red ant (*Oecophylla smaragdina*) were recorded as the invertebrate natural enemies. Whereas, crow pheasant (*Centropus sinensis*), tree pie (*Dendrocitta vagabunda*) and house rat, *Rattus rattus* were recorded as vertebrate natural enemies. Four species of snails *viz. Ariophanta bistrialis*, *Opeas gracile* and *Macrochlamys* sp. and two species of slugs *viz. Mariella dussumieri* and *Laevicaulis alte* were recorded as pests on various crop plants.

Among the different baits evaluated for adult GAS, papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg) was identified as best treatment followed by Papaya leaf pulp (0.5 kg) + jaggery (100 g) + cooked rice (0.5 kg). A similar result was obtained for juvenile GAS and slugs.

Results of the experiment, "evaluation of different traps against GAS" revealed that wet jute sac with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %) and wet jute sac with papaya leaves (750 g) were found to be the best treatments in trapping the snails after first day of exposure. Similar results were obtained after second day of exposure. However, after third day of exposure, mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %) was found significantly superior to other treatments. Hence, mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %) was the best trap against snails.

The laboratory evaluation of seven chemicals revealed that, copper sulphate 5 % was the best treatment against GAS followed by copper hydroxide 4 % and copper oxychloride 4 %. Eventhough, the per cent concentration of chemicals applied were higher, they were able to exhibit significantly higher per cent mortality of GAS. No chemical was able to cause ovicidal action of GAS.

Eight chemicals were evaluated against GAS as poison baits. Among the chemicals evaluated, copper sulphate 5 % showed significant mortality of GAS at twenty four, forty eight and seventy two HAT. Whereas at twenty four HAT, copper sulphate 3 % and spinosad 0.90 ml L^{-1} exhibited higher mortality of GAS. At forty eight HAT, copper sulphate 3 %, spinosad 0.90 ml L^{-1} and carbosulfan 3 ml L^{-1} showed higher per cent mortality. However, 100 per cent mortality of snails were recorded by eight treatments at seventy-two HAT *viz.* spinosad at 0.60 ml L^{-1} and 0.90 ml L^{-1}, carbosulfan at 3 and 6 ml L^{-1}, copper sulphate at 3 and 5 %, chlorpyriphos 6 ml L^{-1} and metaldehyde 6 g m^{-2}.

Fresh aqueous leaf extracts of five plants were evaluated against adults and eggs of GAS in the laboratory. However, none of them were effective to cause mortality of

adults and eggs of GAS even after seventy two hours of expossure. *Azadirachta indica* seed extract @ 15 % showed a higher per cent leaf area protection than all other botanicals evaluated, followed by *Annona squamosa* seed extract @ 15 % and *L. camara* leaf extract @ 25 %.

The experiment to evaluate mortality of GAS using pathogenic nematodes was also conducted. The results showed that the nematodes evaluated *viz. Heterorhabditis bacteriophora, H. indica, Steinernema abbasi, S. bicornutum* and *S. carpocapsae* were unable to cause mortality at 500, 1000, 3000 and 5000 IJ snail^{-1}.

Three entomopathogenic fungi *viz. Beauveria bassiana, Lecanicillium lecanii and Metarhizium anisopliae were* tested against GAS at a spore concentration of 10^7, 10^8, 10^7 spores ml^{-1} respectively. The results obtained revealed that the treated entomopathogenic fungi were unable to cause mortality of GAS even after two weeks of expossure.

Important findings of the investigation were as follows.

- Vakkom and Pulimath panchayaths recorded higher population of adults and juveniles of GAS respectively.
- Flat headed worm (*Bipalium* sp.), grub of firefly (*Oculogryphus pterotus*), red ant (*Oecophylla smaragdina*), crow pheasant (*Centropus sinensis*), tree pie (*Dendrocitta vagabunda*) and house rat, *Rattus rattus* were recorded as natural enemies of GAS.
- *Ariophanta bistrialis*, *Opeas gracile* and *Macrochlamys* sp. were the snails and *Mariella dussumieri* and *Laevicaulis alte* were the slugs recorded during the survey.
- Papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg) was identified as the best bait to attract GAS

- Mud pot with fermented bait and poison (500 g wheat + 200 g jaggery + 5 g yeast, copper sulphate 6 %) was the best trap identified against GAS
- Application of copper sulphate 5 %, copper hydroxide 4 % and copper oxychloride 4 % were found effective as topical application in laboratory against GAS
- Among the chemicals evaluated as poison baits, spinosad at 0.60 ml L^{-1} and 0.90 ml L^{-1}, carbosulfan at 3 and 6 ml L^{-1}, copper sulphate at 3 and 5 %, chlorpyriphos 6 ml L^{-1} and metaldehyde 6 g m^{-2} were found effective in causing mortality of GAS.
- *Azadirachta indica* seed extract @ 15 %, *Annona squamosa* seed extract @ 15 % and *Lantana camara* leaf extract @ 25 % were exhibited higher per cent leaf area protection.
- Among the pathogenic nematodes evaluated *i.e. Heterorhabditis bacteriophora, H. indica, Steinernema abbasi, S. bicornutum, S. carpocapsae* and *Rhabditis sp.* at varying doses, none of them were effective in causing mortality of GAS.
- Among the entomopathogenic fungi evaluated, *i.e. Beauveria bassiana, Lecanicillium lecanii and Metarhizium anisopliae* at varying spore concentration, none of them were effective in causing mortality of GAS

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MANAGEMENT OF GIANT AFRICAN SNAIL *Achatina fulica* (BOWDICH)

by

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(2014-11-168)

Abstract of the thesis

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695522

KERALA, INDIA

2016

A study on "Management of giant African snail *Achatina fulica* (Bowdich)" was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani, Thiruvananthapuram, during 2014-16. The objectives were to study the distribution of *A. fulica* and its natural enemies, if any and to develop effective management strategy using plant extracts, chemicals and pathogenic nematodes.

In order to find out the distribution of giant African snail (GAS), a survey was conducted in ten panchayaths of Thiruvananthapuram district. Among the ten panchayaths surveyed, Pulimath and Vakkom panchayaths recorded highest number of adults and juveniles of GAS respectively. Flat headed worm/ hammer headed worm and crow pheasant, *Centropus sinensis* Stephans were recorded as natural enemies.

The management study included evaluation of different baits and traps for attracting GAS and evaluation of different chemicals, botanicals and pathogenic nematodes against GAS.

Among the different baits evaluated for GAS, papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg) was identified as best treatment with highest number of individuals attracted (11.65). Mud pot with fermented bait (wheat flour 500g + jaggery 200g + yeast) and copper sulphate 6% as poison was found to be superior trap over others, with 20 snails trapped per pot.

Among different chemicals evaluated, copper sulphate 5% showed a quicker mortality (43.07 per cent) at 24 hours after treatment (HAT). The effect was continued and at 72 HAT, copper sulphate 5% shown significantly higher per cent mortality (93.33) over others and which was followed by copper oxychloride 4% and copper hydroxide 4% with, a mortality of 80 per cent. Results of the experiment to evaluate ovicidal action of chemicals against GAS revealed that, none of the chemicals found effective.

The copper sulphate 5% was found to be the best poison bait among different baits evaluated with 80.29 and 88.71 per cent mortality of GAS at 24 HAT and 48 HAT respectively. The treatments: spinosad 45 SC @ 0.60 ml L^{-1} (T2), spinosad 45 SC @ 0.90 ml L^{-1} (T3), carbosulfan 25 EC @ 2.00 ml L^{-1} (T8),

carbosulfan 25 EC @ 3.00 ml L^{-1}(T9), chlorpyriphos 20 EC @ 6.00 ml L^{-1} (T12), metaldehyde @ 6.00 g m^{-2} (T21), copper sulphate @ 3.00 % (T23) and copper sulphate @ 5.00 % (T24) recorded 100 per cent mortality of snails at 72 HAT in the laboratory.

The laboratory evaluation of eight botanicals at varying concentrations revealed that, they were not effective in causing mortality, ovicidal action and antifeedant effect against *A. fulica*. But comparitively higher per cent leaf area protection was observed for *Azadirachta indica* seed extract @ 15 %, *Annona squamosa* seed extract @ 15 % and *Lantana camara* leaf extract @ 25%, among which *A. indica* seed extract @ 15 % was found to be significantly superior to other treatments.

Two species of nematodes from the genus Heterorhabditis (*H. bacteriophora* and *H. indica*), three species from the genus Steinernema (*S. abbasi*, *S. bicornutum* and *S. carpocapsae*) and two species from Rhabditis were tested against GAS. However, these nematodes were nonpathogenic to *A. fuica*.

The study concluded with the following results. Higher population of adults and juveniles of GAS was observed from Pulimath and Vakkom panchayaths respectively. Papaya leaf pulp (0.5 kg) + jaggery (100 g) + wheat flour (0.5 kg) was the best bait evaluated against GAS. Mud pot with fermented bait and poison was superior to other traps evaluated. Copper oxychloride 4%, copper hydroxide 4% and copper sulphate 5% were effective chemicals evaluated against GAS. Copper sulphate 5% was found to be the best treatment among various chemicals evaluated as poison baits. Spinosad 45 SC @ 0.60 ml L^{-1} and 0.90 ml L^{-1}, carbosulfan 25 EC @ 2.00 ml L^{-1} and 3.00ml L^{-1}, chlorpyriphos 20 EC @ 6.00 ml L^{-1}, metaldehyde @ 6.00 g $m^{-2}$and copper sulphate 3% were also identified as effective poison baits under laboratory conditions.