



E-ISSN: 2320-7078

P-ISSN: 2349-6800

www.entomoljournal.com

JEZS 2020; 8(4): 01-06

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Received: 01-05-2020

Accepted: 03-06-2020

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Slug: An emerging menace in agriculture: A review

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Abstract

Most of the terrestrial slugs are potential threat to agriculture across the globe. Their highly adaptive nature helps them to survive in both temperate and tropical climates which is one of the major reasons of its abundant species diversity. It is not only a severe problem in different seedlings of nursery and orchards, also a worry factor for the seeds of legumes sown in furrows. The whitish slimy mucus generated by this pest makes the flower and vegetables unfit for sale. However, despite of its euryphagic nature, very few works have been carried out on slug morphology, biology, ecology, taxonomy and its management in India. This review article tries to integrate the information of economically important slug species of the world as well as India, their bio-ecology, nature of damage, favorable factors with special emphasis on eco-friendly management tactics of this particular gastropod pest.

Keywords: Slug, euryphagic, bio-ecology, management, gastropod pest

Introduction

With a number of 80,000 to 135,000 members, mollusc ranks second largest invertebrate group in the world, out of which 1129 species of terrestrial molluscs are found in India [1, 2, 3]. Under the phylum Mollusca and class Gastropoda, land slugs also contribute significantly in terrestrial malacofaunal diversity. Slug is devoid of backbone and has unsegmented soft, fleshy body with four front tentacles and rudimentary or no shell often enclosed in a visceral hump. Several snail and slug species are considered as notorious pests in agro-ecosystem in different parts of the world due to their rasping feeding behaviour. Corn and soybean crops were subjected to 50-90% yield loss due to slug damage [4]. It has been experienced that one single slug can destroy about 50 wheat seeds in the first week of its sowing. In India, 14 pestiferous slug species have been reported from different diverse habitats like orchards, nursery, playhouses and crop fields [5] among which some are exotic to this land. Moreover, many slug species have been reported as vectors of plant and human diseases. Even though, the pest is significant in terms of its extent of damage in standing crops and quality degrading capacity in agricultural commodities, very limited works have been carried out in the country as a whole. Hence, this review article aims to enlighten the overall slug scenario in the agricultural fields of India as well as abroad.

Species diversity

Among numerous terrestrial slug species across the globe, several species are listed as potential crop pest in both temperate and tropical zones. Members belong to the genera *Deroceras*, *Milax*, *Tandonia*, *Limax* and *Arion* are recognized as the important pestiferous slugs prevailing in temperate climates, out of which *Deroceras reticulatum* and *Arion vulgaris* are the worst pest slug species in Europe [6]. Various workers have reported that under the genera *Deroceras*, *D. reticulatum* has been found very active at low temperature and widely spread throughout Europe, North America, the USA, Australia and New Zealand [7, 8, 9]. *D. panormitanum* also appeared as a major pest in legume seeds, nursery bed and some other horticultural crops in Britain, North America, New Zealand and Australia [6, 10, 11]. *Deroceras laeve* was also noticed as pest in arable crops in several temperate areas. Out of several members of genus *Arion*, *A. vulgaris* was found highly vulnerable to crop due to its role in carrying plant pathogens and its adaptation to dry climates by laying more number of eggs.

However, egg hatching capacity was more in the wetter conditions of Northern Europe [6]. Another species, *A. hortensis* aggregate also caused damage in potato, strawberries, lettuces, wheat and barley fields [6, 12]. In case of family Milacidae, *Milax gagates* and *T. budapestensis* were the most damaging species in temperate region. *Milax gagates* caused serious threat in different countries as an invasive pest, whereas, *T. budapestensis* was also reported as a potential pest of potato because of its soil burrowing nature [13].

Veronicellidae and Ariophantidae are the two most important families of slug under the order Stylommatophora found in tropical areas of the world. Several Veronicellids viz. *Belocaulus angustipes*, *Laevicaulis alte*, *Sarasinula plebeia*, *Veronicella cubensis*, *Veronicella sloanei* etc. have already been considered as serious pests in different crops of tropical areas. *L. alte*, *S. plebeia*, and *V. cubensis* had emerged as very serious problem to both the vegetable and floriculture industry in Hawaii [14]. Some of these slugs were also responsible for causing public nuisance in both urban and suburban areas. In the countries like India, China, Fiji, Malaysia and Sri Lanka, the tropical leather leaf or lined leatherback slug, *L. alte* was found to cause heavy damage in lettuce, spinach, coriander, tobacco etc. [15, 16]. In different parts of Central America, Caribbean leather leaf slug or bean slug, *S. plebeia* has been considered as menace due to its wide host range, primarily in bean crop. Beside this, the species also caused damages in sweet pepper, tomatoes, cucurbits, white radish, red taro, Chinese cabbage etc. in different parts of the world [17, 18]. As reported by USDA (2006) [19] the Cuban slug, *V. cubensis* had gained pest status in many horticultural crops viz., banana, cabbage, cassava, citrus, coffee, eggplant, mango, noni, papaya, pepper, pumpkin, star fruit, sweet potato, taro, yam and some ornamental plants mainly in Hawaii. Another species under *Veronicella*, *V. sloanei* also attacked crops like citrus, banana, broccoli, cabbage, cauliflower, carrot, taro, eddo, eggplant, hot and sweet peppers, lettuce, peanut, plantain, sweet potato, tannia, tomato, yam, beans, peas etc. [20]. In case of some ornamental plants like *Datura*, *Gardenia*, *Hibiscus* sp. and *Bougainvillea* sp., the slug damages the leaves and also debarks stem portions of the plants. However, black-velvet leatherleaf, *B. angustipes* was considered as a potential lawn pest, but it was not so significant in agricultural lands [21]. The second important family "Ariophantidae" includes a yellow-shelled semi-slug, *Parmarion martensias*, a problematic gastropods in the countries like Cambodia, China, Indonesia, Japan, Malaysia, Singapore, Taiwan and Hawaii. It was recognized as a destructive pest of several orchids, other commercial flowers, vegetables, legume crops [16, 22, 23] and plays important role in the transmission of *Angiostrongylus cantonensis*, a parasitic pathogen that causes rat lungworm disease in human [24]. *Ratnadvipia irradians*, another semi-slug species has been reported as endemic to Sri Lanka and found abundantly near the canopies of arecanut, mango and Ceylon breadfruits trees of homestead gardens and also in some rain forests [25].

Considering Indian scenario, out of 14 species of slugs that have already been reported so far, the common garden slug (*Laevicaulis alte*) and brown/black slug (*Filicaulis alte*) are commonly distributed slug species. In Punjab and Himachal Pradesh, *L. alte* is causing major problem in pot-marigold, portulaca, balsam, verbena, cosmos, narcissus, dahlia and lily production [26]. *L. alte* showed maximum feeding, in the early and late hours of the night [15]. In Barnala and Sangrur districts of Punjab, considerable damage caused by *F. alte* has

been noticed in cauliflower, cabbage, broccoli, radish, turnip and arvi cultivation [27]. Jayashankar *et al.* [28] reported three important pestiferous slug species viz. *L. alte*, *D. leave* and *Mariaella dussumierei* from Southern parts of India. Voracious feeding behavior of brown slug, *M. dussumierei* on succulent buds and leaves of vanilla plants was also observed in the Western Ghats [29]. It also caused damage on horticultural crops like coffee, young rubber plants, areca palms, cocoa, banana, black piper, China rose and *Anthurium andraeanum* [30-33]. Naik *et al.* [34] reported the damage incidence of *M. dussumierei* in Marigold in Tumkur district of Karnataka during Rabi season. This slug species was noticed to feed on the buds, flowers, growing shoot tips and foliage of the Marigold plants causing damage upto 15-30% during 2012-13. The mucus secreted by the slugs also reduced the quality of flowers. Directorate of Plant Protection Quarantine & Storage (DPPQ&S) of India also enlisted that gray garden slug (*Decoratus reticulatum*) and spotted garden slug (*Limax maximus*) are two problematic slug species in large scale basil cultivation [35]. Gupta and Oli [36] reported slug *Anadenus altivagus* in Kumaon Himalayan forests ecosystem of India. Of late, *Laevicaulis haroldi* a new terrestrial slug species which was earlier found only in Africa, was first time noticed in Nasik district of Maharashtra in 2014 [37]. This slug species preferred to move on leaves and stem of varieties of vegetation viz. Papaya, congress grass, neem etc. and observed to feed on leaves, flowers and fruits. However, extensive damage caused by *L. haroldi* and *A. altivagus* in economically important crops is not yet reported in India. Other important slugs that are found in India are *Pseudaustenia ater*, *Mariaella beddomei* and *Limax* spp. [38].

Biology

Though slugs are hermaphrodite, but for successful fertilization reciprocal exchange of spermatozoa, i.e. cross fertilization is necessary. However, exceptionally in few species self-fertilization is also observed. Very high humidity (upto 95%) triggers the reproductive behavior of slugs. Reproductive cycle of slug includes five clear phases: courtship, copulation, nest building, egg laying and embryonic development followed by egg hatching [39]. Commonly found garden slug, *Laevicaulis alte* starts to breed generally in the monsoon season. It lays oval, whitish or creamish colored eggs in cluster in moist soil. Eggs masses form ball like structure with the help of an interconnecting thread. Special fecal pellets are deposited on the top of the eggs by the slug itself which help to maintain humidity level. Hatching of juveniles is observed after 9-18 days. The average adult maturation period is 271 days. For egg laying, damp soil in the polybags of nursery plants is very suitable to *Filicaulis alte*. Egg masses are white and spongy with 74-80 eggs per cluster. Newly emerged slugs start feeding immediately. Within 8-9 months, they become mature and start laying eggs twice a year [26]. In case of an oviparous slug, *Sarasinula plebeian*, several matings were noticed even in the same night in laboratory conditions [17]. This species lays eggs in clutches containing average 37 eggs per clutch. Tropical slug, *Belocaulus angustipes* can live for several years and shows its peak activity during night when temperature is in between 68 to 75°F. Being oviparous in nature and the species can lay 1 to 5 egg masses per breeding season. The egg mass was coiled and adhered with the help of gelatinous, fecal-containing strand. Egg hatching occurred within 20 to 28 days depending on the temperature [17, 21, 24, 40]. Another semi-slug,

Parmarion martensi exhibited both cross and self-fertilization and laid eggs 22 to 188 in numbers with 75 to 96 per cent hatching rate [23]. Egg masses contained approximately 10 to 30 eggs but, these were not chained together like other species [41, 42, 24].

Nature of damage

Due to its typical rasping behavior, slug generally makes holes of different sizes in the leaves and tender stems. These holes may be in the middle of the leaf or on the edge. Sometimes, it also damages the seeds shown in the soil. Slug, especially black keeled slug (*Milax* spp.) feeds on seeds of legumes in the furrows. Seedlings and young plants of several horticultural crops are more prone to slug damage and sometimes, they consume the entire seedling. However, cereal crops showed moderate tolerance to slug damage, while canola and lupins were not capable to compensate due to the severe damage observed on cotyledons [26]. Crops belongs to the family Brassicaceae suffer nibbling by slug which makes them unfit for sale. Green asparagus shoots below the soil are mostly attacked by slug pest. Slug sometimes consumes complete pericarp of tomato fruit within an overnight leaving behind the inner core [43]. Slug has also been considered as a notorious pest in strawberry cultivation. According to a report of Institute of Arable Crop Research (IACR), slugs chew holes in ripe strawberries and favor mould growth leading to reduction in market qualities [44]. Reduction of quality of different cut flowers and leafy vegetables due to the whitish slimy mucus secreted by the slugs is also major problem faced by the farmers.

Seasonal activity

Generally, in most of the parts of India, peak period of slug emergence coincides with the onset of monsoon. However, occurrence of several species are being observed throughout the year, mainly in forest and damp areas. Climatic conditions like continuous rain and high relative humidity are the key factors that promote reproduction and fecundity of slugs. However, possible impact of soil factors upon this gastropod pest cannot be denied. Generally, crops grown in relatively heavy soil are more vulnerable to slug damage because this type of soil enhances survival and growth of different slug species [16, 44]. In case of no or reduced tillage system slug is a common problem. Moreover, high organic matter content in the soil also favors the population buildup of slugs.

Management strategies

Slugs in the last few years have become increasingly problematic pests to control in this region. Their infestation has been reported throughout the country and the magnitude of the problem has been quite alarming over the past years. It is rather difficult to eradicate this polyphagous and noxious pest because of its peculiar behaviour and nature of damage on various crops. Successful and at the same time, environmentally safe management of slugs can be accomplished with accurate identification of species, correct selection and proper timing of management strategies. Adoption of appropriate cultural, physical, biological, chemical as well as quarantine measures in a holistic way is very much necessary for the successful management of this problematic terrestrial mollusc pest.

Cultural control: Selected site for kitchen gardens and nurseries should be in sunny area to avoid dampness. Slug

problem is more common in reduced or no tillage cropping system, which can effectively be reduced by deep ploughing the soil at least twice in a year. It generally destroys the egg masses present in the soil and exposes the slugs to the predators. However, abundant vegetation in soil facilitates higher moisture level which makes the land ideal for the multiplication of snails and slugs. Habitat manipulation, clean cultivation, proper weed management are very promising in slug pest control. *D. reticulatum* an abundant slug species found in the grass strips of rape fields showed higher amount of crop damage when crop was one meter away from the grass strips than its greater distances from the strips [45]. Moreover, raising of unnecessary plants between trees and vines not only provides a good shelter belt of snails and slugs but also increases the organic matter content in the soil which is also considered as a key factor of increasing slug population in soil. Therefore, it is suggested to follow trimming, weeding and hand collection practices in timely manner that can effectively decrease the slug population in agricultural land.

Mechanical barrier: Slugs normally avoids dry surfaces. Continuous line of abrasives material such as dry ash and sawdust act as effective barrier against slug movement. However, its durability reduces remarkably in wet or damp environment. Salt barrier is a common practice followed to manage both snails and slugs. Apart from using salt as a barrier material in field, in the countries like Netherlands, dry salt is applied in the soil to get rid of slug damage in asparagus cultivation. However, direct salt application in the soil is not recommended in other crop fields as other crops do not tolerate high salt level like asparagus. It is observed that slugs become less active in bare soil. Hence, a strip of bare soil about 1-1.5 meters wide on the periphery of the kitchen garden can impart some levels of protection against slug movement. Chemicals like copper sulfate or Bordeaux mixture show repellent characteristics against snail and slugs. Consequently, use of such chemicals on tree trunks can repel terrestrial slugs. Nowadays, copper foil taps are also available in the market which can be used around the flowerpots or tree trunk to restrict the slug movement.

Trap technology: Setting of different traps in and around the field is effective to limit slug menace. Smell of beer attracts snails and slug, therefore, use of beer traps in homestead garden is a common practice followed in different countries. Bait trap, trap crop stations or trash trap are also effective for slug management. Bait traps can be prepared by mixing a suitable food attractant (bran, beer, sugar water and yeast mixture or any other preferred food) with molluscicides. Similarly, by placing preferred food sources of slugs (lettuce or strawberry) trap crop stations can be arranged. In different parts of Central America, trash traps are explored to attract bean slug, *Sarasinula plebeian* away from the crop fields [17]. For this purpose, plant residues were collected to make heaps of at least 30 cm × 30 cm × 30 cm. These heaps acted as shelter hub of slugs during day time. However, it is advisable to check the heaps in regular interval as it may serve as ideal breeding site for snails and slugs.

Biological control: Perusal of literature reveals that, in the field of biological control of slugs, notable works have been carried out on parasitic nematodes or some other natural enemies such as sciomyzid flies, carabid beetles, rather than

disease causing microorganisms. Nematode *Phasmarhabditis hermaphrodita* is the most widely used slug killing nematode in different temperate countries which can control adults and juveniles of many pest slug species [46]. However, slugs belong to the genus *Limax* and *Arion* are not susceptible to this parasitic nematode. The bacterium, *Moraxella osloensis* has been found to be symbiotically associated with *P. hermaphrodita*. *M. osloensis* produces an endotoxin which makes this symbiotic association becomes more virulent to pestiferous slug species [6, 47-49]. After invading, it can kill the slug within 4-21 days [47]. Furthermore, larvae of Sciomyzid flies (*Tetanocera* spp.), staphylinid beetle, and adults of carabid beetles (*Cychrus caraboides* and *Carabus violaceus*) are also reported as effective slug killers in different crop fields [44, 50, 51]. Being recognized as a potential slug eater globally, use of runner duck in organic cultivation is very helpful to bring the slug population to a considerable limit.

Legal control: For the effective management of slug infestation, it is very important to check the spread of slugs to unaffected areas. International as well as domestic quarantine measures should therefore be implemented strictly in different countries to check its entry. Also proper inspection must be carried out in case of farm vehicles, farm implements and other farm accessories as they may serve as an ideal carrier of slugs as well as their eggs.

Chemical control: Some of the chemicals are effective to control this species. However it should be advisable to use the chemicals judiciously as the species is abundantly thrive in residential areas where they feed on household waste materials. Metaldehyde 2.5% pellet, a commercially available broad spectrum molluscicide is generally recommended for snail and slug control. Field application of poison baits also gave better result in terrestrial problematic molluscs control. Dichlorvosbait (1 kg wheat flour + 0.2 kg jaggery + 250 ml dichlorvos 76 EC) or methomyl bait (1 kg rice bran + 0.2 kg jaggery + 100g methomyl 40 SP) along with cabbage/ lettuce leaves or split papaya stems (as attractant) can be used in crop fields [52]. Jiggery syrup should be prepared in low heat and mixed with wheat flour/rice bran along with the poison. After making small balls, it should be kept in 10 places in the field with the attractant. However, utmost care and precautions must be taken while preparing the baits and it should be away from the farm animals. Besides, carbamates such as thiodicarb and methiocarb are also act as effective molluscicides. Moreover, to be effective, the molluscicides should be such that it may not get dissolved and washed away by rain because snails are normally active during the rainy season. Keeping in mind about the environmental safety, in recent times, use of iron phosphate is highly recommended in snail and slug management, as it is far safer than the aforementioned molluscicides. Ingestion of baits containing iron phosphate does not cause immediate death of the slugs, rather it ceases feeding behaviour of the pest which leads to ultimate death of the gastropods within 3 to 6 days [24]. Consequently, use of iron phosphate as a safe molluscicide in organic farming is now included in the norms of organic production system by IFOAM [53]. Recently, caffeine has been gaining importance due to its neurotoxic behaviour in snails and slugs [54].

Conclusion

It is noteworthy that, both native and alien terrestrial slug

pests are great menace in agricultural farms, lawns, gardens as well as in public health sector. However, very minimal works have been carried out in slug management aspects as compared to other arthropod pests in the countries like India. Proper identification of the species, extensive studies on microbial and chemical slug control methods with appropriate quarantine measures are necessary for the effective control of pestiferous slugs. Human intervention in slug migration, rapid change in the global climatic scenario, poor crop management tactics etc. may act as catalytic factors in slug population explosion in agriculture as well as urban ecosystem in near future. Therefore, proper awareness about this nuisance pest and adoption of eco-friendly slug management practices in a holistic way will be necessary to solve the problem.

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