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VAGINULID SLUGS IN CENTRAL AMERICA, WITH EMPHASIS ON THE BEAN SLUG *Sarasinula plebeia* (FISCHER)

Alfredo Rueda, Rafael Caballero, Rina Kaminsky and Keith L. Andrews

INTRODUCTION

The family Vaginulidae (=Veronicellidae) (Mollusca: Soleolifera) has a pantropical to subtropical distribution. Of the known ca. 100 species in this family, more than half occur in the Americas. Vaginulid slugs are important in Central America for two reasons. First, they are pests in several staple food and horticultural crops. Second, vaginulid slugs are intermediate hosts of the nematode *Angiostrongylus costaricensis* (Morera and Cespedes) that parasitizes humans. Costs associated with the disease were estimated to be US$5 million annually (Andrews, 1987a).

By 1993, Central America had a population of 28 million people. Of those, 55% live in rural areas and most of them live in poverty or extreme poverty. Dry beans (*Phaseolus vulgaris* L.) are the major source of protein for people in Mesoamerica. Half a million hectares of dry beans are planted annually. Vaginulid slugs, especially *Sarasinula plebeia* (Fischer, 1868), is an important pest on bean crops in the region. Slugs feed on the leaves and stems of young dry bean plants, defoliating and often killing them. Andrews (1987a) estimated that more than 400,000 farmers in Central America suffer economic losses due to these slugs every year. The estimated losses range from US $ 27 to 45 million annually.

The purpose of this chapter is to summarize the research carried out in Central America, principally over the past three decades, that focused on providing the understanding of biology and ecology necessary for the development and implementation of effective management strategies.

HISTORY OF PEST INFESTATION IN CENTRAL AMERICA

Vaginulid slugs are native to Central America, although several of the pest species have been introduced from other regions. Their presence in Central America was first recorded by Heynemann (1885) and Cockerell (1890, 1895). Before 1965, these slugs were considered of minor importance on coffee (*Coffea arabica* L.) in Guatemala (Alvarado, 1939), Nicaragua (Anon., 1953) and Costa Rica (Anon., 1960). Slugs were also reported occasionally on bananas (*Musa acuminata* Colla) in Honduras (J. Osmark, Honduras, 1984, personal communication), on tobacco (*Nicotiana tabacum* L.) in Costa Rica (Anon., 1960) and on dry beans (*Phaseolus vulgaris* L.) in Nicaragua (Anon., 1981) and Costa Rica (Anon., 1965). Most of these records of crop damage relate to the slug, *Diplosolenodes occidentalis* (Guilding, 1825) (Thomé, 1985). The Costa Rican and Nicaraguan references to damage on dry beans were for humid areas at high elevations. In these cases, the damage was attributed to *D. occidentalis* or the slug responsible was not identified.

Andrews and Dundee (1987) reviewed the literature to recreate the apparent spread of *S. plebeia* in Central America (Figure 1). Severe economic damage to dry beans plants caused by vaginulid slugs was reported first in two departments of El Salvador in 1967. These attacks were detected on bean crops around the experimental station of the Ministry of Agriculture in San Andrés, La Libertad. According to Mancía (1971), an unknown taxonomist identified the pest as *Vaginulus plebeius*. By 1970, damage to dry beans was common in all departments of the country (Mancía, 1971).

In Honduras, problems with slugs on dry beans started in 1970 (Anon., 1976). By 1976, these infestations were present in the departments of El Paraiso, Francisco Morazan, Olancho, Ocotepeque and Comayagua. It is believed that at that time slugs were also present in the departments of Lempira and La Paz (Anon., 1976). In addition to the above departments, Córdova (1981) reported these slugs in Cópan, Lempira, Yoro, Santa Bárbara, Cortés, Valle, Choluteca and La Paz. In 1988, Caballero *et al.* (1991) presented a detailed survey of vaginulids in Honduras from field collections made between 1984 and 1988. In this study, four vaginulid species were encountered in Honduras: *Belocaulus angustipes* (Heynemann), *Diplosolenodes occidentalis* (Guilding), *Leidyula moreleti* (Fischer) and *Sarasinula plebeia* (Fischer)(Figure 2).

Slugs, Sarasinula-type, were first reported in the department of León, Nicaragua in the early 1970s (R. Caballero, Honduras, 1989, personal communication). Severe infestations on dry beans were reported during 1973 in the departments of Nueva Segovia, Madrid, Matagalpa, Nueva Guinea and Chinandega. By 1980, the slugs were present in the department of Jinotega, and according to R. Daxl (Nicaragua, 1984, personal communication), were causing considerable damage in the southern departments. Farmers reported *S. plebeia* as a severe pest in several crops, especially squash (*Cucurbita* spp.) in Boaco, Nicaragua, in 1992.

As noted above, minor damage to dry beans has long been known from Costa Rica. This damage was attributed to *D. occidentalis*. However, collections made by R. A. Sequeira (Nicaragua, 1985, personal communication) revealed *S. plebeia* in Costa Rica in 1981, close to the Nicaraguan border. By 1989 this species was widely distributed in Costa Rica (J. Saunders, Costa Rica, 1985, personal communication). In Guatemala, vaginulid slugs have been known since the early 1980s to *cause damage* on dry beans, particularly close to the El Salvador and Honduran borders (Salguero, 1981). To the east of Guatemala City farmers have reported severe infestations since 1976 (K L. Andrews, unpubl. data).

S. Dundee (Andrews and Dundee, 1987) collected *S. plebeia* in Orange Walk, Belize, during 1984. This is the first report of the species in Belize; however, some farmers reported damage to dry beans before that time. The pest status of *S. plebeia* in Belize is not well known (Andrews and Dundee, 1987). In Mexico, damage on dry beans caused by *S. plebeia* has been reported in Chiapas since 1980 (J. Gutiérrez, Mexico, 1985, personal communication) and in Veracruz since 1981 (G. Arcos, Mexico, 1985, personal communication). By 1983, the same species was present in Mérida, Yucatán (Andrews and Dundee, 1987). In Panamá, damage produced by *S. plebeia* was first reported in 1984 (H. Iglesias, Panamá, 1985, personal communication). R. Caballero (Honduras, 1992, personal communication) observed considerable damage to sweet peppers and tomatoes in the province of Los Santos in 1992. The slug is now known to occur throughout Panamá.

The vaginulid slug responsible for the widespread crop destruction in Central America is not native to the region, but was introduced through human commerce (Andrews, 1987a). The 1967 identification of slugs infesting crops in El Salvador as *Vaginulus plebeius* (Fischer) (Mancia, 1971) was subsequently confirmed by S. Dundee and J. W. Thomé (Andrews and Dundee, 1987). In the current systematic concepts of the Vaginulidae, *plebeia* is included in the genus *Sarasinula*. However, there has been much confusion as to the identity of these slugs, primarily due to the absence in the region of taxonomy experts. The taxonomy of vaginulid slugs is based on the morphology of the hermaphroditic reproductive system, and a good knowledge of the comparative differences among species, the variation with stage of maturity, and preservation artifacts, is necessary to make the correct identifications.

Andrews and Dundee (1987) reviewed the literature and concluded that there were five species of vaginulids in Central America. Caballero *et al.* (1991) collected extensively in Honduras from 1984 to 1988 and determined four species: *Belocaulus angustipes* (Heynemann), *Diplosolenodes occidentalis* (Guilding), *Leidyula moreleti* (Fischer) and *Sarasinula plebeia* (Fischer).

1. *Belocaulus angustipes* (Heynemann, 1885) Lopes-Pitoni and Thomé, 1981: This species has a black velvet notum and hyponotum, and black ocular tentacles (Picture 1). The sole is blackish and narrower than any of the hyponotum. This slug was introduced from South America. It is the smallest species in Central America, weighing not more than 1.2 g, and in Central America is known only from Francisco Morazan department in Honduras. It is not important as agricultural pest, but has been found infected by *A. costaricensis* (Caballero *et al.*, 1991).

2. *Diplosolenodes occidentalis* (Guilding, 1825) Thomé, 1985: This species has a gray notum, varying somewhat in intensity, and usually with very small, bright dashes randomly directed (Picture 2). The ocular tentacles are dark. The hyponotum is usually darkly pigmented (Picture 3), but this pigmentation varies with age and among individuals. Immature slugs, weighing less than 1 g, have no pigmentation and occasionally there are adults without pigmentation. The sole is light gray and narrower than the hyponotum. This species reaches a weight and size greater than *S. plebeia*. At present, this species is not considered a pest. It occurs primarily in low abundance in agricultural areas. However, this species has been reported as causing damage in perennial crops in the past (Anon., 1953; Anon., 1960; Anon.,

1965) and has been found infected with *A. costaricensis* (Caballero *et al.,* 1991). According to Thomé (1989) *D. occidentalis* is widely distributed in Central and South America.

3. *Leidyula moreleti* (Fischer, 1871) Thomé, 1971: This species has a light-gray notum, with two parallel stripes which are more defined in the anterior third (Picture 4). The integument at the perinotum is granulated. The sole is light yellow and wider than the hyponotum (Picture 5). Adults are larger than *S. plebeia*, growing to a weight of 9 g. This species is not considered of economic or human health significance because of its low abundance. It has not been found infected with *A. costaricensis* (Caballero *et al.*, 1991). *L. moreleti* is known from México, Guatemala and Honduras (Thomé, 1989).

4. *Sarasinula plebeia* (Fischer, 1868) Thomé, 1971: This species has a gray notum, with minute dark marks without a defined pattern (Picture 6). The sole is narrower than the hyponotum (Picture 7). Adults on average weigh about 3 g, but some individuals grow to 6 g. *S. plebeia* is economically the most important species in Central America. It is a key pest of bean crops in many regions, and also feeds on other horticultural and ornamental crops. In addition, because of its high abundance and wide distribution, it is the most important intermediate host of *A. costaricensis.* According to Thomé (1989), *Vaginula behni* Semper, 1885, *Sarasinula dubia* (Semper, 1885) Thomé, 1972, and *Sarasinula lemei* Thomé, 1967 are junior synonyms of *S. plebeia.*

AGRICULTURAL IMPORTANCE OF *Sarasinula plebeia*

Sarasinula plebeia is the most important pest on bean crops in many regions of Central America. Andrews (1987a) considered the situation of *S. plebeia* to be one of the most significant mollusk infestations in the world. In recent years, *S. plebeia* has assumed pest status on sweet pepper and tomato fruits in Panamá and on cucurbits in Nicaragua (R. Caballero, 1992, personal communication). On dry bean crops, in the last eight years, slug damage and distribution is unknown for the lack of studies in this topic. The authors believe that the pest has perceived in importance for the farmers and scientists due to the outbreak of the sweet potato whitefly (*Bemisia tabaci* (Gennadius)) and geminivirus in the region. Farmers already know the control procedures for the bean slug, but they have few effective alternatives to control the whitefly and geminivirus.

It is important to consider the pest status of vaginulid slugs in the light of the agronomic systems used for maize and dry bean cultivation in Central America (Figure 3). Most dry beans in Central America are relay-planted with maize (*Zea mays*). Maize is planted at the beginning of the rainy season (May-June) and dry beans are planted between the maize rows manually when the maize reaches physiological maturity (August-September). *S. plebeia* abundance is generally very low at the beginning of the rainy season, after a period of some drought lasting 4 to 6 months. The surviving slugs emerge at the onset of the rainy season and feed on broad-leaved weeds and reproduce during the maize growing season. By the time of the bean planting season, the *S. plebeia* populations may be usually very large and can destroy the bean seedlings (Rueda *et al.*, 1987).

Vaginulid slugs are herbivorous, feeding mainly on leaf tissues, buds, soft stems and sporadically on fruits such as bean pods and sweet pepper and tomato fruits. These gastropods have been considered a key pest due their attack on seedlings, they cut new stems of bean plants (Picture 8). Also, when they feed on terminal buds (Picture 9), young plants are irreversibly damaged and die (Caballero and Andrews, 1989).

MEDICAL IMPORTANCE OF *Sarasinula plebeia* AND OTHER VAGINULIDAE

Vaginulid slugs are of medical importance as intermediate hosts of parasitic nematodes, namely *Angiostrongylus costaricensis* (Morera and Céspedes), a natural parasite occurring in mesenteric arteries of rodents and other mammals (Morera, 1973). This metastrongylid nematode causes in humans a disease known as human abdominal angiostrongyliasis, geographically restricted so far to several countries in the Americas, particularly Costa Rica (Morera, 1973).

In rats, the first stage larvae measures 270 mm by 15 mm, are passed out in the feces. Mollusks feeding on these feces ingest the larvae, which migrate to the mollusk's mantle and foot tissues. Here the nematodes moult twice before reaching the infective stage in about 16 - 19 days. Infection of rats, other mammals and humans occurs orally by ingestion of either the infected mollusks or viable larvae in slime-contaminated hands or food. Once ingested, the larvae migrate through the intestinal tissues to the lymphatic vessels in the abdominal cavity, moult twice, and then migrate to the mesenteric arteries. This development is completed by about the 10th day post-infection. Oviposition by the mature female nematodes begin about 18 days after initial infection, with first stage larvae appearing in feces after 24 days (Morera, 1973).

Different genera of vaginulids and other slugs have been found infected in Latin America. *Diplosolenodes occidentalis* was found infected by *A. costaricensis* in Colombia (Malek, 1981). *S. plebeia*, *B. angustipes* and *D. occidentalis* have been found to be infested in Honduras (Caballero *et al.*, 1991). In Nicaragua, the infection of *S. plebeia* varied from 4% in urban areas to 85% in rural areas (Duarte *et al.*, 1992). In Río Grande do Sul, Brazil, infections have been confirmed in *Phyllocaulis variegatus* (Semper, 1985), *Limax flavus* Linnaeus, *L. maximus* Linnaeus (Graeff Teixeira, *et al.*, 1993), *Phyllocaulis soleiformis* (Orbigny, 1835) *and B. angustipes* (Graeff Teixeira, *et al.*, 1994).

The first 31 cases of human abdominal angiostrongyliasis, spanning the period 1951 -1967, were reported from Costa Rica in 27 children and four adults (Céspedes *et al.*, 1967). By 1980, 116 additional cases in children were reported in that country (Loría-Cortes and Lobo-Sanahuja, 1980). The first case of abdominal angiostrongyliasis from Honduras was reported in 1972 (Sierra and Morera, 1972). In 1983, six additional cases were reported (Zúniga *et al.*, 1983) and by 1995 there were 23 more cases (R. Kamisky, unpubl. observ.). Isolated cases of human infection by *A. costaricensis* have been reported from El Salvador (Sauerbrey, 1977), Nicaragua (Duarte *et al.*, 1991, Vásquez *et al.*, 1993) and Panamá (Sánchez, 1992). Angiostrongyliasis is also known from the Caribbean and South America (Kamisky, 1997).

The usual clinical presentation is of appendicitis-like abdominal emergency, accompanied with eosinophilia of 40% or more. There are complaints of abdominal pain localized in the right iliac fossa. Pain is also present on palpation of the abdomen, and a tumor-like mass can be felt in the right lower quadrant. Rectal examination is painful.

Anorexia, vomiting, diarrhea and abdominal rigidity can also be found alone or in combination (Céspedes *et al.*, 1967; Loría-Cortés and Lobo-Sanahuja, 1980). Other descriptions include: yellow granulation of the subserosa of intestinal wall. Eosinophilic infiltration of the appendix and or the lymph nodes (Loría-Cortés and Lobo-Sanahuja, 1980), extra intestinal lesions in the liver and testes (Céspedes *et al.*, 1967), a larva migrans-like syndrome (Morera *et al.*, 1982), an obstruction of the spermatic artery (Ruíz and Morera, 1983), a gangrenous ischemic enterocolitis, acute appendicitis and Meckel's diverticulum-like presentation (Hulbert *et al.*, 1993).

It is unknown why are there about 300 new cases a year of angiostrogyliasis in Costa Rica, while in the rest of the Americas the infection is found sporadically or after diligent revision of pathologic specimens (Morera, 1987). A three year study in Honduras indicated that the population dynamics and interactions among slugs, rodents, humans and the agroecosystem depend, upon the presence of the parasites in rodents and abiotic factors such as humidity and temperature. Without rain farmers do not sow, weeds do not germinate, slugs are inactive and the life cycle of the nematode (*A. costaricensis*) is interrupted (Kaminsky *et al.*, 1995). It does not explain, however, what are the factors in play for increased number of human infections in a particular location.

BIOLOGY, ECOLOGY AND BEHAVIOR

Because of the economic importance of slugs as agricultural pests and as intermediate hosts of parasites, the management of these mollusks is necessary. Efficient management for any pest requires knowledge of its biology, ecology and behavior. Therefore, when *S. plebeia* became a serious pest in Central America, research was initiated to provide basic information from which to develop control strategies.

Belocaulus angustipes has a subtropical native range in South America, and in Honduras occurs only above 800 m. altitude in three different localities in the department of Francisco Morazan. The widely distributed *D. occidentalis* occurs from sea level up to 800 m. Normally found in low numbers, this species has a preference for undisturbed, shaded habitats and is rarely found in cultivated areas. In the north of Honduras, *L. moreleti* has been found at elevations up to 600 m. above sea level. This species, too, occurs at low densities in humid, shaded habitats and is never found in cultivated areas. The most common and abundant species in Central America is *S. plebeia*. It has been found in all departments in Honduras, from near sea up to 1000 m altitude. It prefers disturbed habitats, such as cultivated areas, backyards and gardens.

Vaginulid slugs are polyphagous herbivores, primarily follege feeders. They are nocturnal, hiding during the day under stones, rotten logs and other plant residues on the ground. .*S plebeia* exhibits peak activity between 2 and 4 am. Individuals may travel an averange of 11 m. in the course of a night (Andrews and López, 1987). They may be active during cloudy, humid days. During the dry season the slugs descend into soil crevices up to 1 m. in depth to aestivate. (Andrews *et al.*, 1987). They become active again at the beginning of the raining season, normally in May.

These slugs are most sexually active during the peak of the rainy season (Rueda *et al.*, 1987). Vaginulidae are hermaphroditic, with each individual having both female and male reproductive systems. Reproduction by self-fertilization is common in all species native to Central America, although out-crossing is present in species elsewhere in the Americas. *B. angustipes* and *D. occidentalis* are oviparous; they produce an average of 7 and 33 eggs in each egg clutch respectively (Caballero *et al., 1991*). *D. occidentalis* becomes reproductive at about 7 months of age. *Leidyula moreleti* is ovoviviparous, giving birth to an average of 12 slugs in each of 1-3 clutch per year (Picture 10). Reproduction begins at an age of about 6 months, or when a weight of about 4 g is attained (Caballero *et al.*, 1991; Caballero, accepted).

Sarasinula plebeia is oviparous and produces clutches that average 37 eggs (Picture 11). This species lays 1-2, occasionally 4, egg clutches per year. Under laboratory conditions reproduction begins when the animals are about six months of age, or have attained a weight of 3 g on a bean seedlings diet (Caballero *et al.*, 1991), and up to 16 g on a dehydrated alfalfa pellet diet (Rueda, 1989b). Self-fertilization is common in *S. plebeia* and out-crossing has not been observed in the field. Under laboratory conditions, mating occurs when the animals first reach sexual maturity but not subsequently (Rueda, 1989a). Under field conditions there is no evidence of a sexual or aggregation pheromone. However, Rueda (1989a) observed that most slugs in his laboratory colony of *S. plebeia* copulated several times during the same night at the beginning of their reproductive life, suggesting that a sexual pheromone may be produced.

Studies of feeding behavior in the laboratory (Andrews *et al.*, 1985b) demonstrated that the leaves of some plants species were highly acceptable to *S. plebeia*, while other plants were completely rejected by them (Table 1). They found that *Nicandra physalodes* (L.) Gaertner, *Tithonia rotundifolia* (Mill.) Blake, *Phaseolus vulgaris* L., *Melampodium divaricatum* (Cavanilles) Kunth, *Ipomoea batatas* (L.) Pair and *Brassica oleracea var. Capitata* L. were more consistently and readily accepted. Grasses as well as other plants in the families of the species listed above were consistently rejected. Field observations made by Kaminsky *et al.* (1995) confirmed that more damage occurs on *M. divaricatum* than on *P. vulgaris*. Rueda, *et al.* (1991) showed that *S. plebeia* has the capacity to regulate its food consumption substantially in response to water and nutritional content of the diet. The experiment compared *S. plebeia* consumption and food utilization of a poor quality diet (carrot) and high protein diet (dry alfalfa pellets) prepared in different water dilution. For both diets, slugs were able to increase the food intake as the diet's water dilution increased. The consumption of the alfalfa based diet was on average 5.5 fold more than of the carrot based diet. The difference in consumption between both was attributed to a possible allochemical content in the carrot diet. Slugs on the alfalfa diet continued their growth and the ones fed on carrot diet maintained or lost body weight. In another experiment in Honduras, slugs were forced to consume jack bean (*Canavalia ensiformis* (L.) DC) leaves to see if this cover crop that contains allochemicals allowed the slugs to survive and reproduce. Results indicated the survival and growth rates of slugs fed on jack beans was drastically reduced compared to those fed on dry beans leaves (Rizzo, *et al.* 1994).

SAMPLING AND ECONOMIC THRESHOLDS

Sampling

The fact that *S. plebeia* is active at night and rests underground during the day makes monitoring difficult and costly, compared to other invertebrate pests of dry beans. Population estimates of *S. plebeia* are also difficult to obtain because this slug is mainly active only on nights when the relative humidity is high. On nights when relative humidity drops below 75% slugs are inactive. Day-time sampling of soil is also unreliable because under dry soil conditions *S. plebeia* seeks refuge in humid places under rocks or in soil crevices below practicable sampling depth. Thus, the spatial distribution of *S. plebeia* changes with soil humidity; under high soil humidity slugs are distributed almost in a random distribution, but under dry soil conditions slugs distribution is highly aggregated (Rueda *et al.*, 1987).

Absolute Sampling Methods

From 1979 to 1987 intensive research efforts were made in Central America to develop sampling procedures to measure *S. plebeia* populations, both for scientific and management purposes. The sampling procedure adopted for experiments in Honduras was the visual inspection of 32 soil samples, each of 25x25x25 cm size (Rueda *et al.*, 1987). Data from a two and a half year long population dynamics study showed that in 44% of the sample dates (n = 123), slugs had an aggregated distribution in soil. The general problem with aggregated populations is that many samples are needed for a reliable population estimate. A further deficiency of this sampling procedure is that, when the soil is saturated with water (a common occurance during the rainy season), it is extremely difficult to process the samples and some slugs go undetected.

Rueda (unpubl. data) found soil washing (Hunter, 1968) to allow extraction of slugs from soil, with a recovery rate of 80%. This soil washing technique has yet to be adequately evaluated for the processing of the 25x25x25 cm sized sample units; however, Rueda, *et. al* (1987) found that under dry conditions more than 85% of the slugs occurred in the upper 20 cm of the soil and thus were recoverable.

In the slow flotation method described by Hunter (1968), *S. plebeia* drown before they are able to climb to the surface of the soil sample (J. Garcia, 1985, unpublished data). Rueda tested several methods (unpublished data) to mark *S. plebeia* slugs with the idea of using them for mark-recaptured sampling procedures (Southwood, 1978). Only hot iron brandings of the notum and cutting pieces from the perinotum resulted in marks that remained visible for several weeks under laboratory conditions. Other possible markers were the albino *S. plebeia* slugs found in Honduras (Andrews, 1987b). Unfortunately, slugs marked with these promising techniques have not been tested under field conditions.

Relative Sampling Methods

For the implementation of integrated pest management, relative sampling procedures are considered more pragmatic than absolute procedures, and have been used in conjunction with economic thresholds. Crop damage estimates from the extent of defoliation and yield reduction provide good estimates of the abundance of *S. plebeia* in the field. However, this approach can not be used to predict slug abundance or to determine action thresholds because slug damage on dry bean plants is not reversible. This sampling procedure is better suited to the evaluation of control practices (Andrews, 1985; Wheeler and Peairs, 1980; Sobrado and Andrews, 1985; Meneses, 1985).

Direct nocturnal observations with the help of a flashlight is the most common sampling procedure used to quantify slugs in Central America (Andrews, 1983, 1987b). For research purposes this method has been modified by using an one-meter square wooden frame; all slugs present in the soil surface and over the plants inside the frame are counted. In a population dynamics study this sampling procedure was used weekly for two and a half years, taking 32 observations per sample (Rueda *et al.*, 1987). This procedure has several weaknesses: (i) slug activity depends on the environmental conditions, which may change from night to night, and even within the same night (Andrews and López, 1987), and therefore counts are poor estimators of true abundance; (ii) small slugs are difficult to observe; (iii) a variable proportion of the active slugs are not readily observed due to vegetative ground cover. However, the population dynamics study of Rueda *et al.* (1987) was a key study to design slug control programs for farmers. In the nocturnal samples there were marked differences of slug populations between the growing periods (Figure 4). During the dry season (January to May), when there is no crop or vegetation in the field there were 0.4 slugs/m^2 on average. In this period slugs decreased in number and activity due to the severity of the dry season. At the beginning of the rainy season when maize is planted (June to August) the slug population tripled to 1.5 slugs/ m^2 -. This increment in population density results from the reproduction of the surviving slugs and the ability of the slugs to feed on broadleaf weeds growing under the maize. For the dry bean growing season (September to December) the population again tripled its population to an average of 4.8 slugs/m^2. With this large slug population, the complete defoliation of the dry beans seedlings was likely. The increment of population during this season was due to the mass reproduction of the first generation established in the maize season.

Baited traps have been used extensively to sample slugs populations in Central America. In preliminary studies (Andrews, 1983), pitfall traps baited with a mixture of bran, molasses, beer and carbaryl were used. The trap consisted off a 1 quart oil can with one of its ends removed. This can was buried into the soil and covered with a clay roof tile to avoid rainwater accumulation. With this trap design, seven slugs were trapped for each slug/1m^2 observed with a flashlight the night before. The ingredients of the bait were modified during the course of a series of experiments and in response to farmer comments. The bait now widely used in Central America comprises metaldehyde at 1% as the only active *ingredient*

(Cáceres *et al.*, 1986). A quantity of 5 g of the bait was shown to be sufficient to capture 50% of the slugs present in a radius of 9 m around the trap. For a series of experiments, Cáceres *et al.* (1986) concluded that the metaldehyde-based bait was equally effective when applied in pitfall traps, or under pieces of plywood, fabric sacs or cut weeds, or simply applied as hills in the open field. As a consequence, the recommendations now made to farmers is to apply the bait as hills, without any cover.

For extension purposes it was recommended to use 20 hills each of 5 g of metaldehyde bait for plots up to 0.5 ha. Farmers have been encouraged to set out the baits after 4 pm to avoid drying of the bait in the afternoon sun. Counts of the captured slugs should be made early the next morning; counts made later in the day are likely to underestimate the 'catch' as some of the slugs may have recovered from a sublethal dose of metaldehyde and have escaped. Moreover, small slugs may dry in the sun and thus be difficult to see, or fire ants (*Solenopsis* sp.) may take away the dead slugs. The major constraint in the use of the metaldehyde bait for sampling has been to infrequent availability of metaldehyde in the Central American market. Also, farmers were confused in the use of the same type of bait for monitoring slugs populations and later for control. They usually believed that the sampling was the control measure.

Economic Thresholds

In the initial efforts to develop economic thresholds, Andrews and de Mira (1983) suggested an economic injury level (EIL) of 0.25 active *S. plebeia* per m^2 or 0.4 *S. plebeia* per baited pit fall trap per night, at the time of dry bean germination. They observed that each active slug per m^2 per night resulted in a plant stand reduction of 20% and a yield reduction of 16%. For each slug captured in the baited *pit fall trap per* night, the subsequent plant stand was reduced by 14% and yield by 11% unless control procedures were instigated. Later, Andrews (unpubl.) determined that infestations of 0.12 slugs per m^2 per night during the first 22 to 30 days of the crop was the EIL. However, under typical *S. plebeia* infestations of more than 5 slugs per m^2, control measures applied at the time of crop establishment did not provide adequate slug control to protect the dry bean seelings.

Andrews and Lema (1986) using baited pit fall traps were able to correlate *S. plebeia* populations 10 weeks in advance of the dry bean planting to densities present at plant emergence. Rueda *et al.* (1987) determined that slug active populations averaged 0.4 slugs per m^2 during the dry season, 1.5 slugs per m^2 during the maize season, and 4.8 slugs per m^2 during the bean growing season. These data suggested that control measures should be applied during the maize growing season to reduce slug reproduction and thus maintain a low *S. plebeia* infestation through to the time the dry beans were planted. In a validation study of the EIL on farmers plots with varying degrees of *S. plebeia* infestation, Portillo *et al.* (1986) concluded that each slug captured at the baited hills represented a potential increase in bean yield of 10%. The EIL for *S. plebeia* during the maize season was set at 1 slug per m^2 or 1 slug per bait (at least 10 weeks before dry beans planting). This economic injury level for *S. plebeia* was reduced to 0.5 slug per m^2 or 0.5 slug per trap during the establishment of the bean crop. The reduction of the EIL was made because observational studies suggested that chemical baits were less effective to attract slugs in the presence of bean plants than when they were when used in the maize crop.

CONTROL OF *Sarasinula plebeia*

Biological Control

In Central America a limited number of investigations have been made of natural control agents in *S. plebeia*. Under laboratory conditions, Pinto (1988) observed a blistery disease on the notum of *S. plebeia*. *Citrobacter freundii* and an unidentified·gram negative bacterium were suggested as the causative agents following Kosh postulates. The induced mortality was less than 50%.

In Nicaragua, a population of *S. plebeia* was found to be parasitized by a mermithid nematode (*Hexamermis* sp.) (van Huis, 1981). Later, a mermithid species was found to parasitize more than 50% of *S. plebeia* in the Olancho department in Honduras, but only 10% of the affected slugs died under laboratory conditions. The parasitized slugs had reduced growth and reproduction rates, but after the nematodes (20 cm long) emerged, affected slugs started to gain weight and reproduce (O. Ramírez, Honduras, 1985, personal communication).

In El Paraiso, Honduras, Rueda (1985, unpublished results), found the larvae of an unidentified lampyrid species (Coleoptera: Lampyridae) feeding on *S. plebeia* in the field. In the laboratory, this lampyrid was shown to be capable of killing slugs, but the rate of predation was low at 1 slug every 5 days.

S. plebeia has been considered a recent introduction into Central America (Andrews, 1987a), where it has become a serious pest of dry beans and other crops. This situation contrasts sharply with its low abundance and status as a minor pest in South America, Florida and the Caribbean. Therefore it was considered possible that candidate biological control agents may exist in these areas of low abundance. Bennett and Andrews (1985) and Bennett and Yaseen (1987) searched for natural enemies of Vaginulidae in Trinidad, West Indies, with a view to their introduction into

Honduras. A nematode (*Pnanagrolaimus* sp.) was isolated from slugs that had died in the laboratory, but this species could not be demonstrated to be parasitic or pathogenic in subsequent trials. The adult stage of *Scarites orientalis* (Fabricius), *Athrostictus sp.*, and *Pheropsophus aequinotialis* (Linnaeus) (Coleoptera: Carabidae) fed on *S. plebeia*, but breeding colonies of these beetles could not be established under laboratory conditions.

Exploration in Brazil, Bolivia, Colombia, Puerto Rico and Jamaica (F. D. Bennett, Florida, 1989, personal communication) and Florida, USA (Rueda (1989a), yielded no evidence of attack on vaginulid species by natural enemies in the field. More than 1000 slugs collected from the Americas and observed under laboratory conditions for several generations similarly did not yield any natural enemies. Under laboratory conditions in Florida, Rueda (1989a) conducted a series of inoculation tests with bacteria, fungi, protozoa, free living and entomogenus nematodes, carabid beetles, phorid flies, predatory snails, and flatworms. Again, no viable biological control candidates were found.

Chemical Control

With the invasion of dry bean crops by *S. plebeia* in the 1970s, farmers adopted chemical control as the first, and in many cases, as the only control measure to protect their bean plantings. In a large extension campaign in Honduras, the Government distributed a pre-mixed chemical bait at a subsidized price. This bait was comprised of bran, molasses, metaldehyde and carbaryl (Barletta, 1987). Research on chemical control of *S. plebeia* was initiated in El Salvador by Mancía (1971), who recommended a bait with carbaryl as the active ingredient. Meneses (1985) tested and then recommended the use of granular applications of mephosfolan, but the product was discarded when a survey showed more than 70% of farmers using this product exhibited symptoms of chemical poisoning.

From 1983 to 1986 a series of tests were made by the personnel of the malacology program at Zamorano, Honduras to optimize the recommendations for *S. plebeia* control: Andrews (1985) suggested from a literature review and preliminary experiments in Central America that the basis for chemical control should be baits but, the type, active ingredient, dosages, and application method of the baits to control *S. plebeia* needed to be developed. Sobrado *et al.* (1986) carried out two experiments to determine the effect of metaldehyde, carbaryl, and their mixtures, as active ingredients in a bait. In the first experiment, slugs preferred the bait containing only metaldehyde as the active ingredient. In the second experiment under field conditions, baits with only metaldehyde killed three times the number of *S. plebeia* than did baits containing carbaryl alone and 1.5 times those with a mixture of active ingredients. Portillo *et al.* (1987) tested the effects on *S. plebeia* of several insecticides and herbicides that farmers were applying to bean foliage to control slugs and other pests. The only product that showed some activity as a molluscicide was carbaryl, but slug mortality was low and its use was not recommended.

By 1986 the most common bait formulation used in Honduras was a loose bait prepared with wheat bran (Picture 12). However, in the field the bait lost its efficacy in a day or two. Experiments with chemical preservatives demonstrated that calcium propanate at 1% improved the bait efficacy (Andrews *et al.*, 1986). The wheat bran used as the carrier was at times difficult to obtain on the market. For this reason, Andrews *et al.* (1986) compared locally available substitutes. They found that baits prepared from hay, rice shells, and corn provided the same level of control as those prepared from wheat bran.

Farmers were initially advised to apply bait in hills at the rate of 10 g per m^2 (100 kg per ha) (Meneses, 1985). Field trials by Andrews (1985) indicated that effective control could be achieved with bait hills of 2 g every 4 m^2. For extension purposes the chemical bait recommendations were as follows: for application under maize plants before dry beans are planted, a bait pinch of 2 g every two steps in alternative rows (5 kg per ha) (Andrews and Rueda, 1987a); at the time of planting dry beans, a bait pinch of 2 g, every step in every row of maize (20 kg per ha) (Andrews and Rueda, 1987b).

From 1975 to 1987 the government of Honduras imported metaldehide to prepare the slug bait and sold it at a subsidized price to farmers. Chemical companies did not introduce any product to the country at that time because their products could not compete with the subsidized government baits. After the government stopped the direct importation of metaldehide into the country, agrochemical companies introduced metaldehide baits in a pellet formulation. By the 1997 dry bean growing season, more than 13,000 kg of bait were sold in Honduras (F. Barahona, Honduras, 1998, personal communication).

Coto and Saunders (1985) evaluated 60 species of exotic plants in the laboratory for control or feeding deterrence in *Diplosolenodes occidentalis*. Infusions and extracts were made with various solvents and applied in various doses to bean seedlings. Extracts of *Thevetia peruviana* (Pers.) Schum. leaves and *Canavalia ensiformis* (L.) DC. seeds provided 100% protection of dry beans seedlings. Cantoral (1986) and Cordón (1986) reported that *Nerium oleander* L. and *Jacquinnia macrocarpa* Cav. had some feeding deterrent effect on *S. plebeia*. Later, Sabillón *et* *al.* (1991) demonstrated that *N. oleander*, *T. peruviana*, *Solanum globiferum* Dunal and *Parthenium hysterophorus* L. deterred feeding of *S. plebeia* when extracts were applied to bean seedlings. None of the botanical products tested in those studies worked as molluscicides. To date, none of these plant extracts have been evaluated under field conditions.

Mechanical and Cultural Control

Soil Preparation

S. plebeia populations have been found to be much higher in the maize-bean relay planting system, than in monocropped dry beans planted in ploughed land (Fisher *et al.*, 1986). Soil preparation apparently destroys the slugs and their eggs mechanically and through exposure to the desiccating sun and to predators. However, most farmers in Central America do not use machinery to prepare their land because of the high cost and the topography of the fields.

Pitty and Andrews (1990) summarized the effects on slug populations of tillage treatments applied to the maize-bean relay in experimental plots at Zamorano, Honduras. In the first three years following conversion to zero tillage, slug abundance was greater than in plots with conventional tillage. However, in the fourth and subsequent years, populations were higher in conventional tillage plots. They attributed the initial differences to the absence of the mechanical disturbance and the abundance of broad leaved weeds in the zero tillage plots. The reduction of slugs under zero tillage after the fourth year was attributed to a possible establishment of predators or pathogens, and the possible cumulative effect of chemical baits applied on those plots in the preceding three years.

Manual Killing

One of the earliest recommendations to farmers was to search out and kill slugs at night. Farmers walked the whole plot in search of slugs with the help of a flashlight, and every slug found was killed with a stick or a machete. Some farmers preferred to collect the slugs to show them to the neighbors and then kill them with salt. Sobrado and Andrews (1985) demonstrated that this control technique resulted in a three fold increase in bean yield compared to doing nothing.

Trash Trap.

A control technique that was based on the behavior of *S. plebeia* is the trash trap. In this technique the weed residues obtained from hand weeding the maize fields are raked into hills of at least 30x30x30 cm and left as a day-time refuge for the slugs. Farmers then destroyed the slugs manually twice a week using a machete (Picture 13). Fisher *et al.* (1986) obtained an average bean yield increment of 44% from this control practice in a multi-site validation experiment in Honduras. Miranda *et al.* (1997) reported that Nicaraguan growers captured more than 6,000 slugs and 4 kg of eggs per ha with an estimated slug control of 95% of the population present utilizing the trash trap technique. If the removal of slugs from these trash traps was infrequent, slug numbers tended to increase in the fields due to their reproduction within the trash and thus negate any benefit of this control technique.

Quick Fire

Some farmers prepare the land for relay planting of the dry beans by setting fire to weeds and the dry leaves and tassels stripped from the mature maize plants. Following the fire, the land is raked clean to facilitate the manual sowing of the bean crop. Secaira *et al.* (1986) determined the effect of this practice on slug populations. During the first two weeks after the fire, the abundance of active slugs was reduced by 50% in burned plots compared to unburned plots. In the third week, there were no differences in the number of active slugs between burned and control plots. Slug cadavers were not found after the fire. It is possible that the temporary effect of the quick fire was due to the drastic change in micro climate that triggers slugs to stay inactive underground. Other explanation is the possibly re colonization of slugs from adjacent plots. Secaira *et al.* (1986) thus recommended that the dry beans be planted immediately after the fire to take advantage of the reduced slug activity.

Errázuris (1985) reported that 63% of farmers in Honduras used this technique after they were given extension talks on this topic in 1985. These researchers found, however, that the nitrogen content of the maize plants declined by 10% as a consequence of the fires, and recommendation of this practice was discontinued because it conflicted with soil and nutrient conservation practices practiced by farmers.

Weed Control

Andrews *et al.* (1985b) and Rueda (1989a) showed that *S. plebeia*, while polyphagous, has a strong preference for broad-leaved plants, many of which are common weeds in Central America. *S. plebeia* does not feed on maize or other grasses, even when other food is not available. Studies of *S. plebeia* population dynamics in Honduras (Andrews and Lema, 1986) corroborated the results of the laboratory feeding preference trials. The highest population densities were found in fields in which broad leaved weeds were abundant. Since 1984, chemical control of broad-leaf weeds during the maize growth period has been advocated as an important mean of minimizing *S. plebeia* damage in relay-planted dry beans (Fisher *et al.*, 1986; Andrews and Rueda, 1987a). Fisher *et al.* (1986) reported bean yield increments of 42% on farms that used herbicide treatment in the maize. Del Río *et al.* (1989) showed that maize fields treated with herbicides had 50% fewer slugs at the time of bean planting compared to fields that had no herbicide treatment.

Recent emphasis on less dependence on external inputs has resulted in the introduction of legume cover crops in the maize-bean relay systems. This is primarily to increase fertility and reduce weed problem (Flores, 1994). Under laboratory conditions, Rizzo *et al.* (1994) found that *S. plebeia* was unable to grow or reproduce on a diet comprising the two most common legumes used as cover crops, jack beans (*Canavalia ensiformis* (L.) DC) and velvet beans (*Stizobobium deeringianum* Bort). However, under field conditions *S. plebeia* populations increased more under a velvet bean cover crop than in plots treated with herbicides. This suggests that the cover crop not only provides a good refuge for the slugs, but also does not eliminate the weeds that serve as food for these animals (Rizzo *et al.*, 1994).

IMPLEMENTATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM

As a consequence of the introduction of *S. plebeia* , the area planted on dry beans had by 1975 declined by 50% in some areas of Central America. The first extension campaign to focus on *S. plebeia* control in Honduras was carried out by the Natural Resources Ministry in 1980 (Barletta, 1987). Farmers were by that time reluctant to plant dry beans because most of the crops had been destroyed by *S. plebeia* in the preceding years. The campaign was based on application of a premixed, molluscicidal bait at the time dry beans were planted. An evaluation of the campaign concluded that most farmers achieved poor slug control. The major technical problem identified was the inability of the bait to protect the highly susceptible dry beans in the fields that were heavily infested with slugs. The baits had to compete directly with the beans and broadleaf weeds plants. We called these bait applications "revenge applications" because by the time control was achieved, the damage to the crop had already occured and there was no compensatory response of the damaged dry beans.

The Integrated Pest Management Project in Honduras (MIPH) was initiated in 1983, based at Zamorano, Honduras. Before that date there had been virtually no systematic approach to the development of integrated pest management techniques for the maize-bean relay system in Honduras, or indeed anywhere in Central America. During the first two years of the project, several existing technologies were screened by a socio-economic filter to choose only those technologies that were appropriate to the resource-poor farmers of the region. These technologies were then tested in farmers' fields. Development of new technologies were only attempted when existing ones were found to provide inadequate control of the target pest (eg. the "revenge applications" of baits after bean seedling emergence) or where they were unacceptable to farmers (eg. highly labour intensive methods) (Andrews *et al.*, 1985a).

In 1985, the 'best' technologies for control *S. plebeia* before planting the dry beans were presented to the farmers in a menu format (Pictures 14 and 15). Farmers were able to choose from a range of technologies those that best fit their particular economic resources and pest situation. The strategy behind the suggested technologies was that control of *S. plebeia* should be attempted when the populations are low due to the natural mortality caused by the dry season and before the surviving slugs have started to reproduce in the maize. For the extension campaign the slogan "one dead slug in the first season means 50 fewer slugs in the bean field" was used to motivate farmers to control the slugs during the maize growing season. On 20 farmer cooperatives in Honduras, a demonstration plot was established to compare the projects technologies with traditional crop management practices (Fisher *et al.*, 1986). For farmers with little capital, the manual weeding, trash trap and nocturnal killing technologies were preferred, while farmers with some capital preferred the use of herbicides and chemical baits. In these demonstration plots, all the pest management technologies evaluated reduced the number of slugs, increased bean yields, and produced an economic return to the farmer.

A large scale study was carried out to compare different educational approaches to informing farmers about the biology and ecology of *S. plebeia*, and appropriate control strategies and techniques (Barletta *et al.*, 1987). Farmers increased their knowledge of slugs by 33 to 73%, regardless of the teaching materials used in the presentations. The use of more printed or project material did not increase farmers' understanding. Moreover, the colorful cartoon extension publications (Andrews and Barletta, 1985) were modified to simple realistic drawings with short direct written messages (Andrews and Rueda, 1987ab) in response to farmer feedback.

From 1987 to 1989, the MIPH project continued its research and extension efforts, working in pilot studies in different parts of the country (Del Río *et al.*, 1988; Secaira *et al.*, 1987). In those years the main effort of the MIPH project was the dissemination of the information to public and private extension organizations. We estimate that more that 5,000 farmers received some training in the control techniques developed by the project. This was possible by educating extension personnel through short courses, in-service training, seminars, congress and alliances with extension organizations.

Pitty and Andrews (1990) concluded that the use of herbicides in maize was the most effective way for the control of slugs, but it may not be the only technique needed to reduce slug populations to a sub-economic level. They remarked that MIPH focused too much on the benefits of the herbicides for controlling slugs, but failed to promote this practice as a means to increase maize yields through the reduction of weed competition and the elimination of the lepidopteran maize pest, *Mocis latipes* (Guenée), which only lays its eggs on grassy weeds. They suggested that the herbicide technique should be promoted as 'the stone to kill three birds' (slugs, weeds and *M. latipes*).

Picture list

Picture by Rafael Caballero

Picture 11: The oviparous *Sarasinula plebeia* slug laying an egg clutch.
Picture by Rafael Caballero

Picture 12: *Sarasinula plebeia* slugs killed after ingesting a metaldehyde bait.
Picture by Rafael Caballero

Picture 13: Trash trap. Farmer killing slugs that hidden under hand weeding residues raked into hills.
Picture by Rafael Caballero

Picture 14: *Sarasinula plebeia* slug control alternative menu three months before dry beans seeding stage. A). Slug manual nocturnal killing. B). Herbicide application on maize crop. C). Trash traps. D). Chemical bait application for monitoring and control.
Art by Darlan Matute

Picture 15: *Sarasinula plebeia* slug control alternative menu at dry beans planting time and emergency. A).Quick burning of weeds and maize leaves just before the dry beans planting. B). Slug manual nocturnal killing. C). Chemical bait application for monitoring and control.
Art by Darlan Matute

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Table 1: Average leaf area (mm^2/day) consumed per *Sarasinula plebeia* slug per day in a forced feeding experiment[1].

Plant species	Average consumption/slug (mm^2/day)
Nicandra physalodes	1064 a*
Melampodium divaricatum	1043 a
Phaseolus vulgaris	1008 a
Tithonia rotundifolia	695 b
Commelina diffusa	555 b
Brassica oleracea var capitata	382 c
Lactuca sativa	363 c
Glycine max	243 cd
Ageratum conyzoides	240 cde
Amaranthus hybridus	143 def
Ipomea batatas	98 def
Medicago sativa	83 def
Ipomoea nil	83 def
Citrus sinensis	64 def
Manihot esculenta	63 def
Beta vulgaris	62 def
Sclerocarpus phyllocephalus	30 def
Daucus carota	27 f
Lycopersicum esculentum	26 f
Coffea arabica	25 f
Portulaca oleracea	18 f
Emilia sonchifolia	12 f
Panicum maximum	11 f
Pseudolephantopus spicatus	10 f
Oxalis corniculata	5 f
Cyperus rotundus	2 f
Sorghum bicolor	0 f
Nicotiana tabacum	0 f
Euphorbia heterophylla	0 f
Paspalum notatum	0 f

[1] Obtained with permission from: Andrews, K. L., V. H. Valverde and O. Ramirez. 1985. Preferencia alimenticia de la babosa. *Sarasinula plebeia* (Fischer). *Ceiba* 26, 59-65.

*Means followed by the same letter are not significanty different within each plant especies (p=0.05 Duncan mean separation test)

Figure List and Titles

Figure 1: Years in which vaginulid slugs were reported for first time to cause chronic or severe damage to crops (Central America) or collected for the first time (Yucatán and Belize) [1].

[1] Obtained with permission from: Andrews, K. L. and Dundee, D. S. (1987) Las babosas veronicéllidos de Centroamérica con énfasis en *Sarasinula plebeia* (=*Vaginulus plebeius*). *Ceiba* 28, 163-172.

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Figure 2: Vaginulid slug distribution between 1984 and 1988 in Honduras [1].

[1] Obtained with permission from: Caballero, R., Thomé, J. W., Andrews, K. L. and Rueda, A. (1991) Babosas de Honduras (Soleolifera: Veronicellidae): biología, ecología, distribución, descripción, importancia económica, y claves para su identificación. *Ceiba* 32, 107-125.

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Figure 3: *Sarasinula plebeia* population dynamics with reference to the agronomic systems used for maize (*Zea mays*) and dry bean (*Phaseolus vulgaris*) cultivation in Central America. *S. plebeia* abundance is generally very low at the beginning of the rainy season after a dry period of 4 to 6 months. The surviving slugs feed on broad-leaved weeds and reproduce during the maize growing season. By the time of the bean planting season, the *S. plebeia* populations may be very large and can destroy the bean seedlings.

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Figure 4: Number of active *Sarasinula plebeia* observed per/m^2 during nocturnal sampling sessions between 1984 and 1986 in San Juan de Linaca, Danlí, El Paraíso, Honduras [1].

[1] Obtained with permission from: Rueda, A, Valdivia, A. and Andrews, K. L. (1987) Dinámica poblacional de la babosa del frijol *Sarasinula plebeia* (Fischer) *sensu-lato* en Danlí, el Paraíso, Honduras. *Memorias Resúmenes de la XXXIII Reunión anual del Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA)*. Guatemala City, Guatemala. pp. 118.

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