SPITTLEBUGS: BIOECOLOGY, HOST PLANT RESISTANCE AND ADVANCES IN IPM

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Abstract

Several species and genera of spittlebugs (Homoptera: Cercopidae) are economic pests of grasses in tropical America. These insects compete with grazing animals by reducing forage availability and quality. They may cause serious losses on millions of hectares of improved pastures based on cultivars of several species of *Brachiaria* (signal grasses). Except for the cultivar Marandu, most of the available commercial cultivars of *Brachiaria* are susceptible to spittlebugs. In spite of their economic importance, much research need to be done yet. Such insect-plant system encompasses a diverse group of spittlebug species, a diverse group of forage grass species, which are under different management systems, in a broad range of ecological zones. Control efforts have been directed to host plant resistance, alternative that has been recognized as being of easy adoption and of low cost to farmers. It is probably the best control measure for controlling insect pests in low value crops, like pastures, widely established over vast areas. Screening for spittlebug resistance has been conducted both at CIAT and Embrapa-Beef Cattle Center, and promising accessions have been found. It is important however, that additional biological and behavioral studies of these insects, together with evaluations of other control techniques, like biological control and cultural practices, are also performed. Promising control measures and future research needs are discussed.

Introduction

The beef cattle industry in tropical America, with its extensive production systems, depends on forage for meat production. Several species of the genus *Brachiaria* comprise the most important of these. Because of their excellent adaptation, particularly of *B. decumbens* and *B. humidicola*, to low-fertility acid soils, they have been widely adopted throughout Central and South America. Their introduction, mainly in the savannas, has increased the carrying capacity of pasturelands previously occupied by low-yielding native grasses. Spittlebugs represent the most serious insect pest problem of cultivated pastures in this region. The extensive monocultures of those introduced forage grasses have favored the buildup of high populations of these insects. Several other pasture insect pests have also been recorded (Bergmann *et al.*, 1984; Calderón and Arango, 1985; Calderón *et al.*, 1982; Silveira Neto, 1976; Valério *et al.* 1996). Although some may be a serious threat under certain circumstances, e.g. the burrowing stink bugs of the genera *Scaptocoris* and *Atarsocoris* (Costa and Forti, 1993; Becker, 1996), but the spittlebugs are specially important because of their widespread occurrence, high levels of infestation, and the severe damage they can cause. Spittlebug damage can result in the complete loss of available forage. They not only reduce dry matter production but also forage quality (Valério and Nakano, 1988). Because pastures are considered low-value crops and because they occupy vast areas, chemical control, widely used in high-value crops, is to costly and seldom used for pastures. Therefore, efforts have been directed toward developing effective low-cost control measures that farmers can easily adopt, such as spittlebug-resistant cultivars. Biological control and cultural practices are potentially useful tools and should become important components in any integrated pest management program for controlling spittlebugs in pastures.

Bioecology

Spittlebugs are sucking insects of the family Cercopidae, which undergo simple metamorphosis (egg - nymph - adult). The eggs are elongate; usually pale yellow when first laid changing to a deeper yellow or orange after a few days. Most of the time they are laid at or slightly below soil surface. Generally, under optimum field conditions, hatching occurs within two to three weeks, varying depending on the spittlebug species. Upon hatching, the pasture spittlebug nymphs seek for a suitable feeding site at the base of the plant, where they start sucking the sap. Characteristically more sap is ingested than digested by these insects; being the excess continuously excreted as they feed. This feeding waste, however, is utilized for the nymphs' self-defense. They surround themselves with a frothy, spittle-like mass, produced by adding hundreds of air bubbles (by continuously moving the abdomen and the addition of mucous secretions) to the excreted liquid. As the nymphs grow in size, they may be easily spotted in the field by the frothy mass present at the base of grass stems. In regions where a well-defined dry season occurs, the nymphs, hatching from diapausing eggs, are first seen at the beginning of the wet season. One to several nymphs may be found inside each spittle mass. Inside this moist habitat, they go through several stages, or instars, emerging as adults. The adults present a different behavior from their young forms. They no longer produce spittle living, instead, on the aerial portion of the plant.

The life cycle duration and the number of generations depend on the spittlebug species and on local climatic conditions. In some tropical humid areas, the spittlebugs may be found all year, whereas in drier regions, the infestation period lasts only as long as the local wet season. Sujii (1998) developed a mathematical model of the bioecological processes related to the population dynamics of the spittlebug *Deois flavopicta* which allows the simulation of the annual population sizes of the insect.

In tropical America, these insects range from southern USA to northern Argentina, and are known as "spittlebugs" or "froghoppers" in the USA, "salivazo" or "mión" in Colombia, "candelila" in Venezuela, "mosca pinta" in Mexico, and "cigarrinhas" in Brazil. Each locality has its own, specific, complex of spittlebugs, differing according to genus, the most important being *Zulia*, *Notozulia*, *Deois*, *Aeneolamia*, *Prosapia* and *Mahanarva*.

A number of grasses can host such insects. In the New World tropics, grassland cercopids attack some of the most widely sown grasses of improved pastures, including signal grass, genus *Brachiaria*, (Ferrufino and Lapointe, 1989); Guinea grass, *Panicum maximum*, (Valério, 1992); kikuyu, *Pennisetum clandestinum*, (Fagan and Picado, 1971), and coastal Bermuda grass, *Cynodon dactylon* (Byers, 1965); as well as other graminaceous crops such as sugarcane (Hagley and Blackman, 1966); rice (Nilakhe, 1985); corn (Santos *et al.*, 1982) and turfgrass (Tashiro, 1987). Throughout their range, these insects are regarded as the most destructive pests in pasture and the second most important pests in sugarcane plantations. It is worthwhile to mention that in Brazil the spittlebug *M. fimbriolata* is becoming increasingly important in sugarcane plantations, as burning, a practice traditionally implemented prior to manual harvest of sugarcane, is being replaced by mechanical harvesting (P. S. M. Botelho, personal communication).

Damage

Although nymphal feeding may cause some damage, Byers and Wells (1966) observed that the adults cause the major damage. These authors suggested that the toxic saliva injected during adult feeding interfere with photosynthetic activity. As a result, the leaves first appear whitish; later, necrotic lesions spread longitudinally toward the leaf apex. Under severe spittlebug attack, the entire aboveground portion of the plant appears dry and dead. This does not usually kill the plants, except seedlings, and a regrowth is expected; however, the damage may significantly reduce dry matter production and forage quality (Valério and Nakano, 1988; 1989), lowering the stocking rates of damaged pastures at least temporarily.

Although this severe damage to the plants is obvious, data are still needed to assess the full-season impact on animal production. As Pottinger (1976) pointed out, crop losses from pests are relatively easy to estimate because of their direct effects on crop yield. But assessing pasture pest damage in terms of animal production is complex, costly, and difficult.

Probably, no single method will effectively control spittlebugs; a more appropriate strategy is to integrate various control tactics and to diversify pasture species, thus restricting damage to small areas.

Host plant resistance

Host-plant resistance offers the advantage of being a low-cost method of controlling pasture pests, and one that farmers can easily adopt. A great effort has been devoted to finding grasses resistant to spittlebugs. At first, several grass species from several genera were evaluated (Botelho *et al.*, 1980; Menezes and Ruiz, 1981), some of minor importance in terms of area planted; for example, *Setaria*, *Cynodon*, *Hyparrhenia*, *Digitaria*, and *Melinis*. Of the *Brachiaria* species included in those trials, *B. decumbens* cv. Basilisk and *B. ruziziensis* were rated susceptible, while *B. humidicola* was rated resistant. However, according to Painter's classification of mechanisms of resistance (Painter, 1951), *B. humidicola* is considered tolerant, as it suffers less damage, within certain limits, than more susceptible species under the same insect pressure.

In the humid tropics of Brazil, the susceptible cultivar Basilisk was largely replaced by the tolerant *B. humidicola*; however, despite this tolerance, or perhaps because of it, the spittlebug population in the region reached levels high enough to cause severe damage even in *B. humidicola*.

Cosenza *et al.* (1989) and Nilakhe (1987) reported a high level of spittlebug resistance in *B. brizantha* cv. Marandu. The mechanism of resistance here is antibiosis; that is, the grass has an adverse effect on the survival and development of spittlebugs. The basis of this resistance, however, is not yet fully understood. Although this cultivar has excellent resistance to spittlebugs, it requires more fertile soils than the widely planted *B. decumbens* cv. Basilisk, and has been adopted mostly, but not exclusively, in more fertile areas.

B. dictyoneura cv. Llanero (accession CIAT 6133) was released in Colombia as tolerant of spittlebug. Subsequent studies have shown, however, that this cultivar is an excellent host for spittlebug nymphs (Ferrufino and Lapointe, 1989), and high levels of damage to this grass have been observed in Colombia and Central America.

The introduction to South America of a large collection of new *Brachiaria* germplasm from Africa has stimulated the search for host-plant resistance to spittlebugs. Based on this germplasm, provided by CIAT, field data on spittlebug damage or infestation levels on accessions have been reported from Ecuador (Costales, 1992), Bolivia (Ferrufino, 1986), and Peru (Reátegui, 1990). A screening technique to identify resistance has been developed and used, mostly in the greenhouse (Ferrufino and Lapointe, 1989), but also under field conditions

(Lapointe *et al.*, 1989a). Equally important, mass-rearing procedures have been established (Lapointe *et al.*, 1989b) for a continuous supply of spittlebug eggs, nymphs, and adults for screening trials. An improved and more efficient methodology for massive screening of *Brachiaria* genotypes for spittlebug resistance, the so-called single-tube technique, was developed by Cardona *et al.* (1999). A smaller plant growth unit, supporting a single-stem, is used to rear spittlebug nymphs on vegetative propagules of the tested plants. With this new screening technique it is possible to select for nymphal damage score first, discard genotypes showing high damage scores. It is also used to assess resistance as percentage survival of nymphs, but counting of surviving nymphs are done only on those genotypes with low damage scores. The new methodology, according to the authors, represents a major advance in the development of resistant *Brachiaria* cultivars, whether from germplasm accessions or, particularly, in plant breeding programs. Although the former methods were adequate in screening a finite collection of germplasm accessions, the capacity of the new methodology, as measured by genotypes evaluated per unit time, is at least an order of magnitude greater than the former methods, owing to a combination of lower requirements for inputs of materials, labor and time, resulting extremely useful to manage massive generation of genetic recombinants.

Although several spittlebug species attack *Brachiaria* pastures, *Aeneolamia varia* in Colombia and *Notozulia entreriana* in Brazil have been the focus of the most intensive studies (Lapointe *et al.*, 1992; Valério, 1992). Antibiosis in various *Brachiaria* accessions is being measured by parameters such as nymphal survival, duration of nymphal period, and dry weight of females. More recently, in some evaluations conducted at CIAT, other spittlebug species (*Mahanarva fimbriolata*, *Zulia colombiana* and *Z. pubescens*) have been included (Cardona and Sotelo, 1998).

A large part of the germplasm collection maintained by CIAT has been screened, and sources of resistance identified. In Colombia, Lapointe *et al.* (1992) reported 11 accessions from 6 species of *Brachiaria* as being at least as resistant as *B. brizantha* cv. Marandu. On two accessions of *B. jubata* (CIAT 16531 and CIAT 16203), molting was disrupted, and many nymphs and pharate adults died while still encased within the previous nymphal exuviae. The exact plant component responsible for this antibiotic effect has not yet been identified, but an insect growth regulator is indicated. *Brachiaria* hybrids have also been evaluated and high level of resistance has been reported (Cardona *et al.*, 1998). Several hybrids have shown spittlebug resistance comparable to that of the resistant parent, CIAT 6294 (cultivar Marandu). One, in particular, the hybrid BR 93NO/1371, has been considered even more resistant than the cultivar Marandu.

According to Lapointe *et al.* (1992), at least one other type of antibiotic resistance toward spittlebug exists. In the commercial cultivar Marandu, a toxin or an antifeedant that deters feeding, leading to death by starvation and desiccation during nymphal stage may be involved. Additional studies are required to better understand the mechanisms of resistance.

The resistance of cultivar Marandu is known to be effective against several species and genera of spittlebugs. In Brazil, Valério (1992) selected eight *Brachiaria* accessions all of *B. brizantha*, as resistant, based on nymphal survival and duration of nymphal period of *Notozulia entreriana*. However, he obtained different results, from CIAT, with an accession of *B. jubata* (CIAT 16203). High nymphal mortality of *A. varia* had been observed on this accession in Colombia, but *N. entreriana* showed high nymphal survival rates and a short nymphal period on the same accession (Valério, 1995). This emphasizes the need to determine possible variability in response of resistant materials to different spittlebugs within the species complex in tropical America.

No other commercial *Brachiaria* cultivar or any other forage grass released so far shows spittlebug resistance comparable with that of *B. brizantha* cv. Marandu. After being widely adopted by farmers, this cultivar is now established over millions of hectares throughout tropical America. This huge monoculture, again, represents a serious threat, rendering the production system vulnerable to potential risks. Recently (1998/99), in the State of Mato Grosso, Brazil, continuous area of thousands of hectares established with this cultivar, collapsed due to a prolonged and severe drought period. Additionally and of great concern is the fact that recently frequent and consistent inquires from northern Mato Grosso and southern Pará (Brazil) refer to possible spittlebug damage to the cultivar Marandu. The species of spittlebug (still to be identified) mostly associated with these episodes belong to the genus *Mahanarva*, genus historically associated with taller and more robust grasses like sugarcane and elephant grass (*Pennisetum purpureum*). If this prove to be true, it will be imperative that all the resistant accessions of *Brachiaria* selected so far be reevaluated, now as to spittlebugs of this genus.

Screening for resistance is a continuing process. Escandón D. (1993) studied inheritance of reaction to spittlebug in progenies from interspecific crosses between *B. ruziziensis*, *B. brizantha* cv. Marandu, and *B. decumbens* cv. Basilisk. They showed a relatively high heritability of this character, suggesting a simple inheritance. Presently, Miles and Tohme (1998), at CIAT, are concentrating efforts looking for molecular markers of spittlebug resistance. Hopefully, in the near future, this modern selecting tool, making marker-assisted selection for spittlebug resistance possible, should dramatically improve screening efficiency. Additionally, also at CIAT, efforts are been directed to study the role of endophytes in tropical grasses. These fungi grow intercellularly in tissues, ovules and seeds of infected plants, apparently in a symbiotic association. According to Bacon and White (1994), endophytes can play a role in drought tolerance, competitiveness and persistence, nematode resistance, and broad-spectrum pest and disease resistance. It is also true, as they pointed out, that these same endophytes might also cause undesirable effects on livestock grazing the infected grass. The role of endophytic fungi in *Brachiaria* is as yet unknown. Its elucidation includes actions aiming endophyte detection; development of artificial inoculation methods; characterization of endophytes isolates; taxonomy of endophytes from *Brachiaria*; and effects of endophytes on pathogens and insects (Kelemu, 1998). Through these studies, endophytes were isolated from different species of *Brachiaria*. Preliminary results with *Brachiaria* indicated certain degree of protection by these fungi against a leaf spot disease (*Drechslera* sp.) as well as to the aphid, *Rhopalosiphum maidis*. No measurable effect of endophytes on reaction to spittlebug was as yet detected in genotypes of *Brachiaria* known to be resistant and susceptible to the insect (CIAT, 1999).

About other control alternatives

Chemical control. Insecticides are used in high-value areas, such as forage seed production plots, however, because of their high cost, they are seldom used in pastures. Further, the farmer's interest in chemically controlling spittlebugs does not develop until the damage becomes obvious. But the full expression of, for instance, *Notozulia entreriana* damage in *B. decumbens*, takes about 3 weeks, while the adult lives for only about 10 days (Valério and Nakano, 1992). Thus, proper timing of insecticide application is crucial to effective control, as most of the adult population, which is responsible for the damage, is already dead by the time damage becomes noticeable. Fertilizing the pasture to compensate for spittlebug damage may be more cost-effective than using insecticide, as Prestidge and East (1984) demonstrated for the grass grub, *Costelytra zealandica*, in New Zealand.

Biological control. Biological control holds great potential, because pastures, being perennial crops, provide a fairly stable environment, which should favor the persistence of released natural enemies. Biological control of spittlebugs, however, has been attempted to a limited extent (Barbosa, 1990; El-Kadi, 1977), and little research has been conducted to assess the real potential of this strategy. In Brazil, a major attempt at augmentative biological control, using the fungus *Metarhizium anisopliae* gave inconsistent results, and the method has fallen into disrepute. Despite this being partially due to the poor quality of some of the marketed products, it is also true that emphasis has been given to produce and market only a few *M. anisopliae* strains aiming to cope with a continental wide problem. Definitely, a new approach will be necessary where the spittlebug species complex and the different ecological conditions should be taken into consideration. Additionally, instead of a nationwide approach using a few isolates of the fungus, the search, evaluation, market and technically oriented sales of regionally adapted *M. anisopliae* strains should prevail. Further studies are necessary on entomopathogenic fungi (new formulations, other fungi, e.g. *Batkoa apiculata*) and other natural enemies. For instance, the hymenopteran, *Anagrus* sp., is an egg parasite (Pires *et al.*, 1993); larvae of the fly, *Salpingogaster nigra*, are efficient predators of spittlebug nymphs (Marques, 1988; Páez *et al.*, 1985); adults of the fly, *Porasilus barbiellinii*, prey upon spittlebug adults (Bueno, 1987); larvae of a parasitic fly (Diptera: Pipunculidae) upon spittlebug adult (Peck, 1998a); and ants may influence spittlebug populations through predation of newly emerged nymphs (Hewitt and Nilakhe, 1986).

Cultural practices. Various studies have shown that grazing management (East and Pottinger, 1983) can reduce populations of several insect species. The impact of grazing on insect numbers appears to be indirect, by affecting the microclimate and environmental conditions of the insect habitat (Martin, 1983). Besides being ecologically sound, the use of grazing animals to control pasture pests is also inexpensive, easily applied, and readily understood by farmers.

Attempts have been made to assess the effectiveness of such strategies: observations over a 3-year period by Valério and Koller (1993) showed that both nymph and adult spittlebug numbers (*N. entreriana*) decreased as grazing pressure increased. This finding supports earlier data (Koller and Valério, 1988) on the influence of litter accumulated at soil level on spittlebug populations: significantly lower numbers of spittlebug nymphs and adults were observed over 17 months in pastures where litter was removed. The amount of litter probably increases under low stocking rates. Hewitt (1986) also observed a higher spittlebug egg survival in *Brachiaria* pastures taller than 30 cm, which collected an abundance of litter. Other grazing management studies (Cosenza *et al.*, 1989; Hewitt, 1988; Ramiro *et al.*, 1984) generated contradictory recommendations for the use of grazing animals to control spittlebugs. This strongly suggests the need for further studies. Such a control strategy may be constrained by factors such as weather, topography, restricted application time, and possible detrimental effects of hard grazing and trampling on pasture production (East and Pottinger, 1983); however, this approach may play an important role in combination with other control measures.

IPM strategies for the control of pasture spittlebugs

Controlling insect pests in low-value crops, such as extensive pastures, is difficult and challenging. While, in high-value crops, insecticides are generally recommended for insect control, in pastures, control tools usually are alternative to chemicals. As pointed out by Armbrust and Gyrisco (1975), forage crop, unlike cash crops, is a commodity that nets a small margin of profit per unit area, where the grower benefits from some of the lower-cost control methods such cultural practices; use of resistant plant cultivars; and biological methods including those involving predators and parasites.

The pasture ecosystem represent a relatively long-lasting, perennial system which exists over a wide range of climatic, geographical, and edaphic conditions. The relative condition of stability associated with perennial systems favors the implementation of integrated pest management (IPM) tactics. However, because pastures are established over such a wide spectrum of environmental conditions, and due to the diversity of pasture management systems, and the biological differences in the spittlebug complex, an IPM proposal cannot be identical continentalwide.

Despite the vast literature about grassland cercopids in the tropics, farmers still demand for effective control measures. According to Peck (1998b), short-lived or ineffective control tactics to control grassland cercopids are in great part due to the fact that pasture spittlebugs have been regarded as a homogeneous pest complex. He pointed out the need to elucidate differences among species through examinations of cercopid life styles under local conditions.

Valério and Koller (1993), proposed an IPM program for controlling spittlebugs in Brazil, integrating tactics such as resistant cultivars, pasture management by means of adjusting stocking rates and controlled burning. They recommended pasture diversification including resistant species such as *B. brizantha* cv. Marandu and *Andropogon gayanus* cv. Planaltina; adjusted stocking rate in such a way as to avoid accumulation of leaf litter on the soil surface, without overgrazing the pasture; and controlled-burning, associated or not with disking, at the beginning of wet season to reduce excessive dead material on the soil level. These authors also briefly discuss the proper timing of chemical control. Such tactics were proposed based on studies done with the spittlebug *N. entreriana* in Central Brazil, which can then restrict their application.

Diversifying pastures, using resistant grasses, holds great potential for containing the damage done by spittlebugs. Host plant resistance to spittlebug is probably the best method of control for an insect that attacks pasture, a low value crop, throughout millions of hectares. Although development of resistant cultivars requires several years, according to Kogan (1975), resistance used as a single pest-management factor has achieved some outstanding results due to some desirable features such as (1) specificity to a pest or complex of pest organisms having no direct detrimental effect on beneficial insects; (2) cumulative effect, because the effect on the pest population is compounded in successive generations; (3) persistence, considering that most resistant varieties maintain high levels of resistance for a long time, despite the occasional upsurge of biotypes; (4) harmony with the environment, since no unnatural elements are used; (5) ease of adoption, once developed resistant cultivars can easily be incorporated into normal farm operations; and (6) compatibility with other tactics in pest management. Over the last fifteen years, the greatest contribution toward spittlebug control in tropical America was the release of the resistant commercial cultivar *B. brizantha* cv. Marandu. A huge monoculture with this grass was then established and, today, it seems that, at least in certain areas, its resistance is being threatened by a different spittlebug species. This fact, however, reinforces the need for new alternatives of spittlebug resistant cultivars (ideally including different genera of forage grasses). Some promising accessions are currently under field grazing trials and new *Brachiaria* cultivars should be released in the near future. A new spittlebug resistant cultivar of Guinea grass, *P. maximum* cv. Massai was recently released in Brazil (Euclides *et al.*, 2000).

Efforts on biological control of spittlebugs in pastures have been restricted to entomopathogenic fungi, particularly *M. anisopliae*. However, new isolates of regionally adapted *M. anisopliae* and technically oriented sales of a better fungus formulation are imperative. Further, for rather stable ecosystems like pastures, introduction and colonization of *M. anisopliae* for long-term spittlebug control should be considered. Other fungi, like *Batkoa apiculata*, responsible, sometimes, for widespread natural control of spittlebugs, should also be evaluated. Considering the prevailing extensive production systems, it must be kept in mind that, in spite of the fact that entomopathogenic fungi fit perfectly in an IPM program for spittlebug control, they also carry the onus of being costly and dependent on special application equipment, despite all the advantages they may present in relation to chemical insecticides. The exploitation of predators and parasitoids for spittlebug control is very promising; being the need for complementary studies on such natural enemies a must.

Cultural practices include a list of measures mostly related to pasture management. Bio-ecological studies as to the main spittlebug species are necessary and should result extremely useful when delineating cultural practices for their control. For example, a pasture management practice should be avoided if it is known to be potentially favorable to the insect. Some of these practices, e.g. adjustment of stocking rates, may adversely affect the spittlebug habitat. According to Suber *et al.* (1985), spittlebugs tend to build up in the lush growth of under-utilized pastures. Whatever has been done so far concerning cultural practices affecting grassland cercopids is yet too little and this line of research remains almost unexplored. As mentioned before, any effort in this line must seriously consider existing behavioral differences among spittlebug species. Controlled burning, another cultural practice, although being a common tactic among farmers, particularly in Brazil, with some known impact on spittlebug populations, should be avoided as much as possible, considering the overall undesirable effects to the environment.

Chemical insecticides, due to economic and environmental restrictions, have been seldom implemented for spittlebug control. There are cases, however, such as forage-seed production plots, when insecticides may be economically feasible. As previously mentioned, whether in seed production systems or regular pastures, proper timing of insecticide treatment is crucial, and monitoring of the spittlebug population will be necessary. It is important to recall that pastures are also subject to other insect pests; when insecticides are applied to pastures predators and parasitoids are reduced. This may result in more frequent and damaging insect pest problems in the pastures later in the season.

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