Potential of *Smicronyx spp.* (Coleoptera: Curculionidae) As Biological control Agents of *Striga hermonthica* (Del) Benth and *Alectra vogelii* Benth (Scrophulariaceae) In Burkina Faso (West Africa).

By

Lenli Claude Otoidobiga.

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements of the degree of Master of Sciences (M.Sc.)

Department of
Natural Resource Sciences.
McGill University,
Montreal, Québec, Canada.

June, 1997.

0-612-44238-1

Short title

Potential of *Smicronyx* spp. against witchweeds.

Dedication

To the memories of my father, Otoidobiga Tabidia, and Mother, Louodano Pabado. To my wife, Sawadogo G.Sophie and My Children, David, Cécile Harmonie, Armande and Ingrid. To all the peasant farmers in West African Semi-Arid Tropics, who every year helplessly observe the suppression of their crops by *Striga spp.*

Table of contents

List of figures

List of tables.

Abstract

The potential of *Smicronyx umbrinus* Hustache and *Smicronyx guineanus* Voss (Coleoptera: Curculionidae) as biocontrol agents of *Striga hermonthica* (Del) Benth was investigated at both population levels of *Striga* and *Smicronyx spp.* in the field in Burkina Faso. High population levels of *Smicronyx* spp. resulted in higher percentages of seed-pod galls although the weevils' adult populations decreased during *S. hermonthica* seed capsule production. *Smicronyx* spp. were observed galling *Striga aspera* (Willd) Benth capsules ca. 60 days before *S. hermonthica* emerged in sorghum fields. The weevils also galled *S. hermonthica* stems at soil level and *Sm. umbrinus* was found to be the main species causing this symptom. *Smicronyx* spp. also galled *Alectra vogelii* Benth stems, *Smicronyx dorsomaculatus* Cox being the main species attacking this parasitic weed. Another *Smicronyx* species not yet described was collected on *A. vogelii*. Stem galls appeared to be more effective nutrient sinks than fruit galls. The weevils alone did not have sufficient impact to be considered successful biocontrol agents for *S. hermonthica* but they could contribute to an integrated control strategy against *Striga*. *Smicronyx spp.* have a good potential as biocontrol agents for *A. vogelii*.

Résumé:

Le potentiel de *Smicronyx umbrinus* Hustache et de *Smicronyx guineanus* Voss (Coleoptera: Curculionidae) comme agents de lutte biologique contre le *Striga hermonthica* (Del) Benth a été étudié au niveau des deux populations de *Striga* et *Smicronyx spp.* au champ. Les densités croissantes des populations de *Smicronyx* spp. ont causé des taux de galls de capsules plus élevés bien que les populations adultes de *Smicronyx* déclinèrent au cours de la fructification de *S. hermonthica*. Les *Smicronyx* ont émergé environ 60 jours avant l'apparition de *S. hermonthica* dans les champs de sorgho. Durant cette période ils ont causé des galles sur le *Striga aspera*. Quand *S. hermonthica* émergea, les *Smicronyx* formèrent aussi des galles sur ses tiges au niveau du sol. Les larves de *Sm. umbrinus* étaient les plus nombreuses dans les galles des tiges. Les *Smicronyx* ont causé aussi des galles sur les tiges de *Alectra vogelii* Benth. *Smicronyx dorsomaculatus* Cox était la principale espèce attaquant cette mauvaise herbe parasite. Une espèce de *Smicronyx,* non encore décrite, a été découverte sur *A. vogelii*. Les galles des tiges semblent plus nuisibles à *S. hermonthica* et à *A. vogelii* que les galles de capsules. Mes résultats montrent que les *Smicronyx* ne causent pas suffisamment de dommages pour être considérés seuls comme agents de lutte biologique contre *S. hermonthica* mais ils pourraient contribuer dans le cadre d'une stratégie de lutte intégrée à réduire son impact

sur les cultures. Leur potentiel contre *A. vogelii* est plus important.

Acknowledgments

This research was founded by a scholarship awarded to Lenli Claude Otoidobiga by The International Institute of Tropical Agriculture, Ibadan, Nigeria.

Directors, colleagues and friends in Burkina Faso.

I am indebted to Dr. Abdoussalam Sawadogo, Chef du Programme de Recherches sur les Cultures Maraîchères, Fruitières et Plantes à Tubercules (CMFPT, INERA) Burkina Faso and Dr. Paco Sérémé Directeur de l' Institut National de L' Environnement et de la Recherche Agricole (INERA, Burkina Faso), for requesting the scholarship to IITA for me. I am indebted to Dr. Traoré Doulaye without whose support much of the field work could have not been completed. Special thanks to Ouédraogo Christophe, Traoré Salou for help with transportation facilities, to Bambara Issa, Bambara Oumar, Yaro Romain and to Tiemtoré Marcel for help in collecting data. My gratitude is extended to the farmers of Matourkou, Sisalia and Toussiana who graciously accepted that I investigated in their fields. Overall, my gratitude and love to my wife, my Children and brothers whose solidarity in my endeavor had made this task a success. Thanks to all those who have helped in this work and whose names I have not remembered at the time I was writing this thesis. Forgetting is not a voluntary act and I wish they will understand and accept in these terms my gratefulness.

Directors and staff at IITA

I express my gratefulness to Mr Mathias Zweigert, former Chief of the Office of Technology Transfer Unit at the Plant Health Management Division (IITA/PHMD), Cotonou, Benin, for having facilitated this award and all IITA Managers for their effort to widespread biological control into Africa. I am grateful to ITTA/PHMD staff whom I met and shared experiences several times in Burkina and elsewhere in the course of our collaboration. Special thanks to Dr. W.N.O Hammond IITA/PHMD regional research coordinator, Dr. Chris Lomer IITA/ LUBILOSA Project Manager for his friendship and Dr. Armand Paraiso for his collaboration. Thank to Mr. J.L. Gulley, Program Leader, Training, and Mr. Chris Okafor for the management of the scholarship.

Supervisors and staff at McGill

I express my sincere gratitude and admiration to Dr. Charles Vincent which support has been essential for my registration and success at McGill. I thank him for his continuing support, suggestions and key role in helping me writing and carrying out in the allowed eighteen months by IITA, a proposal that met McGill requirements. Thanks is also due to him for diligently and constantly putting so much effort to review the numerous versions of the manuscripts and the thesis. I am grateful to Dr. Robin K. Stewart my co-supervisor for his attention, kindness, enlightening comments and guidance during this study. My deep gratitude is due to Dr. D. J. Lewis, Chair of the Department of Natural Resources Sciences for his understanding. I am profoundly indebted to Mr. Allan Davis for teaching me English and helping me pass the TOEFL test. Special thanks to Marie J. Kubecki for her kindness and welcome, to Joan Teneyck for managing the scholarship account and to Pierre Langlois for his assistance in seminar slide making.

External scientists

I am particularly indebted to Dr. Josiane Paré, Université Picardie Jules Verne, Amiens for having supported the cost of the histological studies in Amiens, France. Unfortunately the hypothesis investigated at Amiens, (the possible lowering of the viability of the seeds of the capsules situated above seed-pod galls on the same floral spike) had not yielded significant results worth publication. Thanks is specially due to her for her kindness during my stay in her laboratory and for her so many kind gestures. I am grateful to Isabelle Pronier who kindly offered me most of the literature references cited in this thesis. I am specially grateful to Dr. Donald M. Anderson, Systematic Entomology Laboratory, USDA, Washington, DC, for identifying *Smicronyx* adults and larvae and for his enlightening comments on the manuscript. Thanks to Dr A. Raynal-Roques, Museum National d' Histoire Naturelle de Paris, for confirming *Alectra vogelii* identification.

Claims to originality:

In my opinion the following findings bring original knowledge about the potential of *Smicronyx* spp. to control *Striga hermonthica* (Del.) Benth and *Alectra vogelii* Benth.

1. First demonstration of the relationship between population levels of *Smicronyx* spp. and percentages of *S. hermonthica* seed-pods galled in the field.

2. First estimate of *Smicronyx* female reproductive success in *S. hermonthica* seed-pod galls in the field.

3. First report of *S. hermonthica* stem galls at soil level in Burkina Faso, due to *Sm. umbrinus* Hustache and *Sm. guineanus* Voss, 88% of the stem gall larvae (70 out of 80 larvae identified), being *Sm. umbrinus* and first assessment of the frequencies of these stem galls in the field.

4. First report of *Sm. dorsomaculatus* Cox, *Sm. guineanus* Voss and *Smicronyx* sp. galling *A. vogelii* Benth stems in the world, 71% (41 out of 57 larvae identified) being *Sm. dorsomaculatus* Cox.

5. First description of the morphology of the stem galls of *S. hermonthica* and *A. vogelii* due to *Smicronyx* spp.

6. First assessment of the impact of *Smicronyx* spp. stem galls on the growth and seed production of *S. hermonthica* and *A. vogelii*.7. Overall this is the first study of the impact of *Smicronyx* spp. on *S. hermonthica* at the population level and the first observation that *Smicronyx* spp. can efficiently control *A. vogelii*.

Introduction

Witchweeds (*Striga* spp.) are notorious parasitic weeds known for their disastrous impact on food production in the Tropics. Although much effort has been devoted to their control, little has been achieved toward the ultimate goal of their eradication. In the USA, where billions of dollars have been spent every year since 1956, the eradication of *Striga asiatica* is still not complete (Eplee and Langston, 1991). Developing countries cannot allocate such amounts of resources to the control of *Striga* spp.,and eradication is an unlikely feasible goal in these countries. Therefore, the objectives sought by research programs against *Striga* in the developing world are essentially to keep its impact on crop production under the economic threshold. Reportedly, efforts have focused on 1) the reduction of the amount of new seeds added to the soil each year, 2) the reduction of the seed stock already in the soil, 3) integrated control measures combining both approaches (Siegfried, 1994). Although effective methods have been demonstrated in laboratories and research stations, economically feasible techniques at the level of small farm holders are still lacking. The present research achieved in 18 months of academic, field and laboratory work aimed to evaluate the potential of *Smicronyx* spp. as biological control agents of *Striga hermonthica* (Del) Benth in farmers' fields because *Smicronyx spp.* are cited among the most promising biological control candidates of this parasitic weed (Greathead, 1984; Traoré *et al.,* 1996). Our main hypothesis was that, in addition to the destruction of seeds in galled capsules, the quantity and the viability of seed of capsules situated above galled capsules could be lowered. Using histological techniques, investigations yielded no significant results to support that hypothesis. The work presented here deals with 1) the relationship between *Smicronyx* spp. population levels and *S. hermonthica* seed-pod galling in the field and, 2) stem galls of *S. hermonthica* and *Alectra vogelii* Benth due to *Smicronyx spp* .

The present thesis format accepted by the Faculty of Graduate Studies and Research and the Department of Natural Resource Sciences, Macdonald Campus of McGill University, requires the full citation of the five indented paragraphs below of the guidelines of Thesis preparation (Manuscripts and Authorship) of the faculty of Graduate Studies and Research, (in order to inform the external examiner of Faculty regulations).

> Candidates have the option of including as part of the thesis, the text of a paper(s) submitted or to be submitted for publication, or the clearly-duplicated text of a published paper(s). These texts must be bound as an integral part of the thesis.
>
> If this option is chosen, connecting texts that provide logical bridges between the different papers are

mandatory. The thesis must be written in such a way that is more than a mere collection of manuscripts; in other words, results of a series of papers must be integrated. The thesis must still conform to all other requirements of the "guidelines for thesis preparation". **The thesis must include:** A table of contents, an abstract in English and French, an introduction which clearly states the rationale and objectives of the study, a comprehensive review of the literature, a final conclusion and summary, and a thorough bibliography or reference list.

Additional material must be provided where appropriate (e.g. in appendices) and in sufficient detail to allow a clear and precise judgement to be made of the importance and originality of the research reported in the thesis.

In the case of manuscripts co-authored by the candidate and others, **the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent.** Supervisors must attest to the accuracy of such statements at the doctoral oral defense. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to make perfectly clear the responsibilities of all the authors of the co-authored papers. **Under no circumstances can a co-author of any** component of such a thesis serve as an examiner for that thesis.

I followed the rules of scientific writing given in "How to write and Publish a Scientific paper" (Day, R. A., 1994). I wrote each chapter to be presented to a scientific journal according to the editorial guidelines of that journal. Chapter I will be submitted to Entomophaga (France). Chapter II, will be submitted to Insect Science And Its Application (Kenya). All chapters were reviewed by my supervisors, Dr. C. Vincent and Dr. R. K. Stewart. Chapter one and two were commented by other scientists upon request. All papers are co-authored by my supervisors. Chapter II will also be co-authored by Dr. Josiane Paré.

Voucher specimens of larvae and adult *Smicronyx* were deposited to the Systematic Entomology Laboratory, USDA, National Museum of Natural History, Washington, D. C., USA and to the Biosystematics Research Center, Agriculture Canada Ottawa, Canada. Galled *A. vogelii* plants were deposited at the Museum National d' Histoire Naturelle de Paris, France.

I : Literature review

1.1 Insight on *Striga spp.* and *Alectra vogelii* Benth.

Striga spp. are obligate parasitic weeds of tropical cereals and legumes. The common name "witchweed" ascribed to these weeds befits the debilitating and "bewitching" effect they inflict on host plants even before they emerge from the soil. Because witchweeds parasitize important food crops, they are economically important production constraints in much of Africa and Asia. Cereals and legume crops vulnerable to *Striga* species are the major source of energy and protein in the diets of hundreds of millions of people in the semi-arid tropics.

The impact of *Striga* is compounded by its predilection for attacking crops already under moisture and nutrient stress, conditions which prevail throughout the semi-arid tropics (Ejeta *et al.*,1992). Moreover, the problem is further compounded by the changes in the traditional cultural practices due to the increasing human population pressure on lands. In Africa, traditional practices consisted of crop rotation from plot to plot and long fallowing periods when the fields become heavily infested by *Striga* (Butler, 1989). Now, with population growth, the scarcity of land forces subsistence farmers to cultivate infertile soils with limited inputs and resources. Farms become rapidly heavily infested by *Striga*, leading to migrations into new lands, which under similar practices will again become heavily infested (Ejeta *et al.*,1992). The *Striga* problem has become epidemic, presenting a desperate situation to small subsistence farmers.

Eradication of *Striga* in Africa does not seem to be a feasible goal, but innovative farming practices sustained by integrated approach measures will help minimize the negative impact of *Striga* on crop yields. This integrated control package may include chemical inputs directed to the weaknesses of *Striga*, agricultural practices, genetic control practices and biological control. Each component of the integrated approach requires a sound knowledge of the biology of *Striga*.

A. vogelii is emerging threat to leguminous crops in Africa south of the Sahara. Very few is known about its biology and potential impact on crops.

1.1.2. Biology of *Striga* spp. and *A. vogelii*.

The genus *Striga* belongs to the family of the *Scrophulariaceae*. *Striga* plants have green leaves and brightly coloured flowers. Botanically, the genus is characterized by opposite leaves, irregular flowers with a corolla divided into a tube and spreading lobes, herbaceous habit, small seeds, and parasitism (Musselman, 1980). *Striga* seeds are tiny, some 0.30 mm long and 0.15 mm wide. Each *Striga* plant can produce up to 40,000 seeds, depending on the species and growth conditions (Ejeta *et al.*, 1992).

S. genesrioides (Willd) Vatke and *S. asiatica* (Willd)

Benth are highly self-pollinating whereas *S. hermonthica* is believed to be an obligate out crosser (Musselman and Hepper, 1986). These pollination mechanisms may result in host-specific races and have significant bearing on host plant resistance and even on potential adaptation of the parasite to new hosts (Parker and Reid, 1979)

Striga species and the other species of the Scrophulariaceae have a common characteristic in that their parasitic life cycles are close biologically to those of their host plants. In addition, *Striga* species are adapted to the conditions of the semi-arid tropics. Longevity of seeds in the soil has been estimated but with different results. Pieterse *et al.* (1996) in Kenya, Gbehounou (1996) in Benin reported that the longevity of *S. hermonthica* seeds is about two years. These authors stated that the viability of up to 20 years generally evoked in the scientific literature may be valid for *S. asiatica* but not for *S. hermonthica*. Gbehounou *et al.* (1996) and Pieterse *et al.* (1996) reported that *S. hermonthica* seeds germination is bimodal in Kenya and Benin: small amounts can germinated from December to April immediately at the end of the crop season in which they were produced. This germination period ends by April. The highest rate of germination starts at the beginning of the wet season in May and most of the seeds germinate or lose their viability as a consequence of the conditioning for germination due to the moisture and the absence of reversion to the original dormant condition for *S. hermonthica* seeds. Vallance (1950), found that *S. hermonthica* seeds could remain viable in the soil for 20 years. He suggested that seeds preconditioned for germination enter a state of "wet dormancy" from which they may return to dormancy if not exposed to a germination stimulant and that this mechanism helps building an increasing seed bank. All the authors report that a pre-conditioning in moist conditions is required to enable *Striga* seeds to germinate after exposure to stimulants from a host plant.

Upon germination, *Striga* rootlets close to a host root develop an organ of attachment, the haustorium, which forms a morphological and physiological bridge between the host and the parasite. As in germination, the formation of haustoria has been found to be under the control of an external chemical signal produced by the host roots (Edwards, 1979; Okonkwo, 1966; Lynn and Chang, 1990). The chemical signals for germination and haustorial initiation are different from each other.

Striga spp. produce roots which penetrate the host roots along with the primary haustorium (Musselman, 1980). Numerous *Striga* plants may penetrate and attach to a single host plant, influencing the degree of infestation and the extent of crop damage.

The three economically important *Striga* species have a broad host range. *S. hermonthica* and *S. asiatica* commonly parasitize species of Poaceae including sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br], maize (*Zea mays* L.), rice (*Oryza sativa* L.) and sugarcane (*Saccharum spp*). *S. genesrioides* parasitizes dicotyledonous species, primarily cowpea [*Vigna anguiculata* (L.) Walp], tobacco (*Nicotina tabacum* L.), and sweet potato (*Ipomea batata* L.). Host specificity (interspecific variability) is thought to be based on meeting the need for germination, attachment, penetration and the overall requirement of the parasite. Host plants may supply *Striga* with other compounds such as hormones (kinetin, IAA), in addition to water and minerals. However, *Striga spp.* may vary in these requirements as well and exogenous compounds may be essential to some parasitic species and not to others. Wilson Jones (1955); Bebawi (1981); Parker and Reid (1979), Combari (1986) reported intraspecific variation in *S. hermonthica* affecting either sorghum or millet in Sudan, Burkina Faso and West Africa.

Striga has an extraordinary elasticity and capacity to adapt to new host species. Wilson Jones (1955) observed that *S. hermonthica* successively adapted to new crops through slow but gradual buildup of new "biological forms" in Sudan. Doggett (1984) and Parkinson (1989) reported its progressive adaptation to new crops including peanut in West Africa. Such a capacity for adaptation has enlarged the geographical area infested and increased the economic importance of *Striga* *spp.* and particularly of *S. hermonthica*.

Litterature about *A. vogelii* biology is lacking because this witchweed has emerged as a threat to crops only in these very recent years.

1.1.3. Geographical distribution and economic importance of *Striga* spp. and *Alectra vogelii*, Benth.

Striga is native to the grasslands of the Old World tropics, reaching its greatest diversity in Sub-Saharan Africa. The occurrence of economically important *Striga* species is now reported on 59 countries of Africa and Asia (Sauerborn, 1991). There are said to be 50-60 species (Ejeta *et al.*,1992) of *Striga*. Among these three species are recognized as the most economically important because of their impact on crops. *S. asiatica* (L.) Kunze, affects cereals crops in Africa and Asia. It was recorded in 1956 in the USA but is now undergoing eradication there (Eplee and Langston, 1991). *S. gesnerioides* is very serious on cowpea, peanut and tobacco in Africa and Asia. *S. hermonthica* is the most economically important species of the genus in Africa. *Striga* is distributed in more than 40% of the arable land south of the Sahara (Moob, 1989). In West Africa, 48% of the grain fields are infested (Sauerborn, 1991). *Striga* infests ca. 21 millions ha in Africa. Overall, grain production is threatened in the world over an area of ca. 44 millions ha situated in the distribution zone of *Striga spp.* This represent 3.2% of the arable lands of the world (Sauerborn, 1991).

Yield losses to damage by *Striga* have become very heavy. In countries such as Burkina Faso (Niekiema, 1992; Combari, 1986), and Ethiopia and Sudan (Ejeta *et al.*, 1992), losses of 65-100% of harvest are common in heavily infested fields. In West Africa, the yield losses average 24%, the loss of total grain production amounts to 12% which represents 4.1 millions tons of grain (Sauerborn, 1991). Lagoke *et al.* (1991), estimated annual cereal grain losses associated with *Striga* damage at about 40% when averaged across Africa. The overall loss of revenue is estimated at 2.9 billion $US (Sauerborn 1991) to 7 billion (Mboob, 1986). *Striga* has become the greatest biological constraint to food production in Africa.

A. vogelii parasitizes leguminous crops such as cowpea (*Vigna anguiculata* L.) and peanut in Africa South of the Sahara. The yield of these crops is low (i.e.100 to 200 kg/ha) (Singh and Emechebe, 1991) partly because they are parasitized by *A. vogelii*. Such low yields do not provide enough income to enable farmers to use herbicides and fertilizers. Infestation of cowpea and peanut by *A. vogelii* has recently become very heavy in Africa i.e. 8 *Alectra* shoots/peanut plant (Salako, 1984).

1.1.4. Combating *Striga* spp. and *A. vogelii* in Africa

1.1.4.1. Classical control methods

Striga control methods basically aim at increasing crop yields. They may be categorized into those that 1) seek to reduce the amount of new seeds added to the soil each year e.g. hand-pulling and herbicide use, 2) aim to reduce the seed stock already in the soil e.g. trap and catch-cropping or rotation or 3) involve integrated control measures that combine both techniques, e.g. a combination of host plant resistance, chemical and cultural methods (Siegfried, 1994). Although many of the methods are effective in controlling the parasitic weeds, they have not been adopted to any appreciable extent by farmers because they are not economically feasible at the small farm holders level in West African Semi-arid Tropics (WASAT) which systems are mainly survival based systems. Siegfried (1994) mentioned constraints such as land tenure and the lack of relevant information on the economic threshold level that could guide *Striga* control decision making. Cardwell et al. (1991) discussed different socio-economic circumstances under which *Striga* control methods are likely to be adopted in the WASAT. Survival farming strategies cannot afford to invest for long-term benefits which is the philosophy required for leading *Striga* eradication programs in the developed countries.

Chemical control methods, with either pre-emergence or post-emergence herbicides, are aimed at stopping *Striga* seed production. They have minimum benefits in protecting the currently infested crops. Several years of no or low seed production may be required to significantly exhaust the *Striga* seed bank in the soil. Herbicides that can protect the current crop are still not available (Eplee, 1984) because part of the damage to the crop is caused before the witchweed emerges. A sensible way to protect a crop from *Striga* is to deplete the soil of its seeds and unfortunately, there is still no economical way to kill seeds in the soil. The control success achieved in the USA is due the long-term use of seed killing material such as fumigants and germination stimulants, notably the use of ethylene (C_2H_4) and "false host" crops. It took decades of years and has been a very expensive program, not affordable for poor countries (Eplee and Langston, 1991).

Alternative control methods are suggested to meet subsistence farming' s financial capacity. These control methods are only palliative, stopgap measures that do not solve properly the problem and are difficult to apply in many cases:

- Trap cropping involves growing a very susceptible host, and ploughing it down before the *Striga* has reached the flowering stage. Unfortunately, subsistence farmers can spare neither the land nor the labour to do this.

- Several false hosts capable of germinating *Striga* seed but not hosting it have been identified (Doggett, 1984; Ouedraogo, 1996). Some of them that are crops (cotton, groundnuts) do not germinate sufficient quantities of *Striga* seeds. Those that do germinate appreciable quantities (*Euphorbia spp, Crotalaria sp,*) of seeds are not crops, and thus, unlikely to be economic for the smallholder farmers.

Hand-pulling can be effective but is labour demanding when large area are to be cleaned up. Furthermore, the hand-pulling period of *Striga* occurs at the peak of other activities in the fields.

Smith et al. (1993) developed a model showing that *S. hermonthica* would be eradicated by a control method formerly used by the farmers, viz the non availability of a suitable crop or crop rotation for five to six years. Unfortunately population pressure on available land has precluded the continuation of these rotation practices in the WASAT.

Biological control as part of an integrated control of *Striga* may lead to success but this is not yet widespread in the WASAT. Biocontrol strategies in which agents are introduced or released each cropping season (inundative control) are analogous to technologies that requires labour, and possibly access to markets and cash for obtaining the input. However, classical control methods in which the biocontrol agent becomes a sustainable part or self-perpetuating in the biosystem would be acceptable (Cardwell *et al.,* 1991).

1.1.4.2. Biological approaches

The potential of natural enemies of *Striga* to be used as biocontrol agents in the WASAT is being evaluated. These agents include both micro organisms (such as fungi and bacteria) and herbivorous insects. The efforts are focused on the survey of indigenous agents to select those with high potential and host specificity.

Among micro-organisms, numerous fungal antagonists, *Alternaria spp. (A. alternata, A. chlamidospora), Aspergillus spp., Bipolaris spp., Curvilaria spp. (C. eragrotidis and C. lunata), Cercospora spp., Drechslera spp., Fusarium spp., (F. oxisporum, F. nygamai, F. equisiti (Corda) Saccardo, and F. verticilliodes), Macrophina phaseolina, Paecillomyces lilacinus, Phoma sorghina, Rhizopus spp.,* and *Verticillium lecanii,* have been cited as potential biological control agents of *Striga* spp. (Abbasher *et al.,* 1996; Ciotola *et al.,* 1995; Sauerborn *et al.,* 1994; Nag Raj, 1966, Zummo, 1977; Kirk, 1993, Abbasher and Sauerborn, 1992;). Recent data indicate that *Fusarium* is the most prevalent genus and *Fusarium oxysporum* the predominant species (Abbasher *et al.,* 1996). Further work is in progress to evaluate the efficacy of these organisms in the field. If their efficacy is satisfactory, such organisms already present but causing relatively low control of the witchweed in natural conditions will be used as bioherbicides in an inundation strategy, requiring the bioherbicide to be released every season. This strategy would necessitate access to the market and certainly financial resources to procure the input. This is a major constraint to *Striga* control in the WASAT. Repetitive inundation releases of microorganisms must be carefully investigated prior to any large scale spraying, as the WASAT environment is already weakened by recurrent problems such as drought, locusts and other diseases. It would be highly injurious to this weakened environment if a control strategy backfired.

Numerous insects species feeding on *Striga spp.* have been collected, notably in India (Khan and Murthy, 1955) and Eastern Africa (Greathead and Milner, 1971). Among these, *Smicronyx spp.* are considered to be the most important (Greathead, 1984). A single species, *Smicronyx albovariegatus* which galls all parts of the plant is reported from India on *S. asiatica*, but unfortunately it was estimated to have little effect on its overall production (Sankaran and Rao, 1966). In Africa, several *Smicronyx* species have been reared from stem or fruit galls. Although a number of species have been described, mostly from adult specimens collected without associated host plant records, it is not possible to obtain a name for all of them at present (Greathead, 1984) and data about their potential are lacking.

1.1.4.3. Potential of *Smicronyx spp.* as biological control agents of *Striga spp.* and *A. vogelii* in Africa.

Species of *Smicronyx* attacking *Striga* spp. are usually host specific at the genus level and the timing of their life cycle and the number of generations per year depends on the life cycle of their host plants (Greathead, 1984; Traoré, 1995). Only one attempt at classical biological control has been made so far using *Smicronyx albovariegatus* Faust from India. This species was released on *S. hermonthica* in Ethiopia at Humera on the Setit River close to the Sudanese border, and at the Kobbo in the Welo province of Sudan (Greathead, 1984). Subsequent surveys concluded that this species failed to establish.

There are at least six indigenous species of *Smicronyx* associated with *Striga spp.* in Africa (Bashir and Musselman, 1984). They are of particular interest as biological control agents, as they are likely to be host specific and some species are specialist fruit gallers.

Observations on *Striga spp.* infestations by *Smicronyx spp.* in western Africa frequently report up to 84% (Traoré, 1995). Williams and Caswell (1959) in Nigeria, Traoré (1995) in Burkina Faso stated that the weevils appear to attack only the fruits and Jost et al. (1996) found that the mean infestation intensity of one *Striga hermonthica* plant (number of seed capsules per *Striga* plant transformed into galls) was 77.3%. The weevils reduced the overall *Striga* seed production by about 17.4% in Northern Ghana.

The incidence of *Smicronyx spp.* in East Africa is variable (Greathead and Milner, 1971). In Northern Uganda galls were found on *S. hermonthica* at seven out of 12 localities and on *S.asiatica* at five out of 14 localities. Root galls were seen on *S. asiatica* at three out of five localities in southeast Tanzania, and at two out of three in western Tanzania.

Greathead and Milner (1971) estimated the number of plants infested by *Smicronyx spp.* in Eastern Uganda in July 1965. The infestations varied from 10 to 100% with an average of 32.6 to 62.5% for all the localities. In Tanzania these infestations fluctuated from 1.25 to 90%.

Infestation levels on individual plants also varied from 2 to 16 galled seed-pods per plant. The number of seed-pods galled per plant seemed to depend on the age and size of the plant, as large vigorous plants appear to be more heavily galled.

Seeds pod galling by *Smicronyx spp.* appears to have little impact on plant growth and seed production as one single capsule may produce several hundred seeds. Even if many of the seeds pods would be infested, those remaining would produce large numbers of seeds. Also the root galling species on *S. asiatica* does not affect the vigour of the plants (Greathead and Milner, 1971).

The prolific seed production of *S. hermonthica* and the long viability of its seeds that lead to the rapid augmentation of the seed bank in the soil hampered the effectiveness of *Smicronyx umbrinus* in the model elaborated by Smith et al. (1993) to investigate its potential in Mali. The model showed that *Sm. umbrinus* used as the sole control agent, would have to destroy up to 95 % of seeds each year to reduce the emerged plant density to 50%. Any failure or low effectiveness of *Smicronyx* in a single season would allow a dramatic increase in the *S. hermonthica* seed bank. Not only is a high level of seed destruction required, but it must be maintained from season to season. The model indicated that used in conjunction with others methods such as a four year crop rotation, 22% of seed destruction by *Smicronyx* each year is sufficient to reduce the density of emerged *S. hermonthica* to 50%. Smith and Webb (1996) subsequently found that *Sm. umbrinus* needs to destroy 70 to 80% (instead of 95% previously estimated) of capsules each year to reduce the equilibrium level of *S. hermonthica* by 50%.

The effectiveness of *Smicronyx* could be improved by the lowering of *Striga* seed viability. The recent findings of Gbehounou *et al.* (1996), Pieterse *et al.* (1996) indicating that *S. hermonthica* seed viability does not exceed two years in the WASAT reinforces the prospect that *Smicronyx* could be part of integrated control programs.

It is now generally agreed that no single method will effectively control *Striga spp* in the WASAT (Lagoke *et al.*, 1991). In the United States where eradication of *S. asiatica* is still an objective, it has taken decades (from 1956 to date), considerable resources and a combination of methods including quarantine, soil fumigation, germination stimulants (ethylene), cultural practices and herbicides to attain this result (Eplee and Langston, 1991).

This is the first record of Smicronyx spp. attacking *A. vogelii* (D. M. Anderson, personnal communication). Estimation of their potential is lacking and no economically control method of this witchweed is yet available. Efforts aim at breeding resistant varieties (Singh and Emechebe, 1991) but none is yet available for use at the farmers' level.

Chapter I Relationship between *Smicronyx Spp.* (Coleoptera: Curculionidae) and galling of *Striga hermonthica* (Del) Benth (Scrophulariaceae) in farm fields

To be submitted to Entomophaga.

Authors: L. C. Otoidobiga, C. Vincent and R. K. Stewart.

Abstract

Smicronyx weevils (Curculionidae) have been cited as potential biocontrol agents of *Striga spp.*, yet information on their impact on *Striga hermonthica* in the field is still fragmentary. Investigations were conducted in six farm fields (1.5 to 3 ha) in Burkina Faso. The objectives of this study were: 1) to study adult *Smicronyx* population dynamics during *S. hermonthica* seed-pod production, 2) to assess the impact of different population levels of *Smicronyx spp.* on *S. hermonthica* capsule production and, 3) to estimate *Smicronyx* female reproductive success in seed-pod galls. A Univac portable sampler was used to sample adult *Smicronyx spp.* and *S. hermonthica* densities were assessed using a 1 m^2 metal quadrat. Fifty *S. hermonthica* shoots per field were sampled each week. *S. hermonthica* shoots on average produced ca. 24 seed capsules each while female *Smicronyx* galled ca. 12 to 32. Seed-pod galling alone was not sufficiently high to be considered as a successful reduction factor for *S. hermonthica* seed production in natural conditions. *Smicronyx spp.* adult populations decreased during the *S. hermonthica* capsule production period. Increased population levels of *Smicronyx spp.* resulted in higher percentages of *S. hermonthica* seed-pod galls suggesting that augmentative techniques, if used as part of an integrated control could be a worthwhile strategy.

Introduction

Witchweeds (*Striga spp.*) (Scrophulariaceae), are obligate parasitic weeds that threaten grain production over an area of ca. 44 million ha in the Tropics, i. e. 3.2% of the arable lands of the world (Lagoke *et al.*, 1991). In Africa they are present in more than 40% of the arable land south of the Sahara where they cause severe crop losses to cereals and legumes, estimated at 3 to 7 billion $US per year (Sauerborn, 1991). Among witchweeds, *S. hermonthica* (Del.) Benth is the most injurious species. In countries such as Burkina Faso (Niekiema, 1992; Combari, 1986), Ethiopia and Sudan (Doggett, 1988), crop losses of 65-100% due to *S. hermonthica* are common in heavily infested fields. In West Africa yield losses average 24%, and losses of total grain production amount to 12%, i. e. 4.1 millions tons of grain (Sauerborn, 1991).

Striga control methods aim at increasing crop yields. Although many of the available methods are effective in controlling the parasitic weeds (Siegfried, 1994), they have not been adopted to any appreciable extent by peasants because they are not economically feasible at the small farm holders' level. Biological control methods in which the agents become established in the environment are highly desirable in the African socio-economic context (Cardwell *et al.*,1991). Indigenous natural enemy species are potential candidates for augmentative control programs (Greathead, 1984).

Smicronyx weevils (Curculionidae) are considered to be potential biocontrol agents of *Striga spp.* (Bashir, 1987; Greathead, 1984). Traoré *et al.* (1996a) suggested that *Smicronyx umbrinus* Hustache and *Smicronyx guineanus* Voss have the potential to control *S. hermonthica* because 1) they are specific to the genus *Striga*, 2) they gall its capsules and 3) their life cycle is well synchronized to those of witchweeds. Larvae develop in *Striga* seed-pod capsules, eating the seeds and producing galled capsules. No viable seeds remain in the galled capsules (Pronier and Letierce, 1995). Although both *S. hermonthica* and *Smicronyx spp.* are found together in the field (Traoré *et al.*, 1996a), modelling studies suggest that heavy seed-pod galling (70-80%) is required each year to result in a 50% reduction of *S. hermonthica* (Smith and Webb, 1996). However information on the impact of *Smicronyx spp.* as a biological control agent of *S. hermonthica* in the field is still fragmentary.

Our objectives were 1) to study adult *Smicronyx* population dynamics during *S. hermonthica* capsule production, 2) to assess the impact of different population levels of *Smicronyx spp.* on *S. hermonthica* capsule production, 3) to estimate *Smicronyx* female reproductive success in seed-pod galls in the field.

Materials and methods

S. hermonthica shoots and *Smicronyx spp.* adult populations were sampled in 6 farmers' fields at Toussiana (fields 1 and 2) Sisalia, (fields 3 and 4) and Matourkou (fields 5 and 6) located respectively at 55, 13, and 15 km West of Bobo-Dioulasso, Burkina Faso (West Africa). In each locality two fields were chosen after estimation of *Smicronyx spp.* population levels using a Univac portable sampler as described below. The fields ranged from 1.5 to 3 ha in size and were sown with *Sorghum bicolor* (Moench) intercropped with peanut (*Arachis hypogea* L.) using local farming practices. No pesticides, hand pulling or any other control method were used in these fields.

Before the emergence of *S. hermonthica* in cultivated crops in farmers' fields, *Smicronyx* adult populations were monitored as they occurred on *Striga aspera* (Willd) Benth which parasitized weeds in nearby fallow fields. Monitoring of *Smicronyx spp.* on *S. aspera* was started in June and stopped late August when *S. hermonthica* emerged in cultivated crops in farmers' fields. Weekly sampling of *Smicronyx* and *S. hermonthica* started when the first capsule galls caused by *Smicronyx* were recorded and encompassed the period of *S. hermonthica* capsule production that lasted from September to October.

At each sampling date, the densities of *S. hermonthica* in the fields were evaluated using a 1 m^2 metal quadrat. The metal quadrat was thrown at random in the field until the optimum sample numbers determined from a chart developed by Traoré *et al.* (1994) was reached. To achieve a precision level of 20% of *S. hermonthica* populations, preliminary estimations indicated a required average of 40 m^2 quadrats for each field on each sampling occasion, making a total of 200 m^2 quadrats in fields 1 and 2, and 240 m^2 quadrats in the fields 3 to 6. One or two *Striga* plants were randomly sampled in each m^2 quadrat until a total of 50 shoots per field was collected on each occasion. These shoots were observed in the laboratory the following day to record the percentage of shoots bearing seed-pod galls, the number of seed-pods produced, the number of seed-pod galls, and the number of *Smicronyx* larvae.

A Univac portable sampler (Burkard Company Ltd, Woodcock Hill Industrial Estate, Rickmansworth, Hertfordshire WD3 1PJ, England) was used to sample *Smicronyx spp.* adults. A 120 mm diameter suction cone was placed on a *Striga* shoot at ca. three cm above the ground. The cone was left in position allowing ca. five seconds of suction before being removed. Ten suctions constituted a sample unit. To provide a precision level of 20%, the number of required sample units was determined after a preliminary density had been estimated using ten sample units (Traoré *et al.,* 1994). A mean number of 40 sample units were sampled per field on every sampling date, amounting to a total of 200 sample units in each of the fields 1 and 2, and 240 in each of the fields 3 to 6. Adults weevils were counted and released in situ.

The percentages of attacked capsules were transformed using arc $\sin\sqrt{\%}$. A three way factorial analysis of variance (ANOVA, SAS General Linear Model Procedure, SAS Institute Inc., 1989), and Student Newman-Keuls test were performed among the different sites, weeks and densities of *Smicronyx spp.* adult populations. Voucher specimens of larvae and adult *Smicronyx* were deposited to the Systematic Entomology Laboratory, USDA, National Museum of Natural History, Washington, D. C., USA and to the Biosystematics Research Center, Agriculture Canada, Ottawa, Canada.

Results

Smicronyx spp. were present on *Striga aspera* by June in the adjacent fallow fields. Surveys done in early July 1996 indicated that *S. aspera* seed-pods were attacked by *Smicronyx spp.* larvae identified as *Sm. umbrinus* and *Sm. guineanus* (Donald M. Anderson, personnal communication). We observed *S. hermonthica* emerging in sorghum fields on August 18 at average densities ranging from 17 to 38 shoots per m^2 quadrat, (i.e. 15 to 55 shoots/m^2). On average 24 seed capsules were produced per shoot (min 0, max 91). In all fields, *Smicronyx spp.* adult population levels decreased during the *S. hermonthica* fruiting period (Fig.1).

Thirty five out of 41 (85%) adults *Smicronyx* sampled on

S. hermonthica in the fields were *S. guineanus,* and six (15%) *S. umbrinus.* The mean densities of this mixed population ranged from 0.16 to 0.71 adults/*Striga* shoot in the fields (Table 1). Nine per cent of attacked capsules containing full grown larvae were not transformed into galls; these attacked capsules have been included in the estimate of the percentage of galls. In addition to galled seed capsules six to 20% of *Striga* stems were also galled at soil-level depending upon the fields.

The percentages of galled capsules caused in the fields ranged from 6.4 to 24.3% (Table 1). Increased population density of *Smicronyx* adults resulted in higher percentages of seed capsule galls (Fig. 2). The ratios, number of seed-pod galls/number of *Smicronyx* ranged from six to sixteen (Table 1). This represents 25 to 67% of *S. hermonthica* shoot capsule production. The lowest ratio was recorded in field 3 although this field had the highest density of *Smicronyx* (0.71) per shoot (Table 1). However in this field we also observed 28% of shoots bearing stem galls at soil level which contained multiple *Smicronyx* larvae (up to 23) per gall while percentages of stem galls were lower (6 to 10%) in the other fields. Most of the shoots bearing stem galls at soil level desiccated before flowering.

The mean infestation intensities of *S. hermonthica* shoots (number of seed capsules per *Striga* shoot transformed into galls) ranged from nine to 25%. The average percentages of shoots bearing seed pod galls ranged from 42 to 79.2%. Significant differences in the percentages of galls induced were observed among the fields (p = 0.005, n = 30) and weeks (p=0.02, n= 30).

Discussion

Adult *Smicronyx* were observed on *S. aspera* in fallow fields adjacent to crops in early July and on emerging *S. hermonthica* among crop plants in late August. *Smicronyx spp.* presence on *S. aspera* in adjacent fallow fields lasted up to 60 days before the emergence of *S. hermonthica* in crop fields. Thirty to 40 mm of rainfall is required for West African *Smicronyx* species to emerge at the beginning of the wet season (Traoré *et al.*,1996b). This precipitation level, known as "useful precipitation" also corresponds to the beginning of the growing season of cereal crops in Burkina Faso. When exposed to crop root chemical exudates, *S. hermonthica* seeds germinate, attach themselves to the host roots, and develop underground for 4 to 7 weeks before emerging (Berner *et al.*, 1995). In contrast to *S. hermonthica, S. aspera* can germinate in the absence of a host plant (Combari, 1986). This species is therefore available to emerging *Smicronyx* when the required rain fall level (30 to 40 mm) is reached. The finding of *Smicronyx spp.* larvae in *S. aspera* seed-pods under production before *S. hermonthica* emergence in fields indicates that the weevils were reproducing on this species. Traoré *et al.* (1996a) observed *Smicronyx spp.* on sentinel plants 16 days before the emergence of *S. hermonthica* in farmers fields. Our results allow no explanation of the declining of *Smicronyx spp.* adult populations during *S. hermonthica* fruiting. Data about possible migration between the fallow fields and crop fields are not available. However the time they spent on *S. aspera* suggests that these populations were aging and thus subjected to increased mortality.

The densities (0.16 to 0.71) recorded in natural conditions were low compared to those (15 to 25) reported by Bashir (1987) in Sudan, but corresponded to in average attacks of 42 to 79.2% of shoots resulting in 6.4 to 24.3% of galled capsules. The ratios, number of seed-pod galls/number of *Smicronyx* ranged from six to sixteen (Table 1). This represented 25 to 67% of *S. hermonthica* shoot capsule production. These levels of galling attained in natural conditions are not sufficiently high to consider seed-pod galling alone as a successful reduction factor of *S. hermonthica* seed production.

The differences of the percentage of galls among the sites indicate that increased densities of *Smicronyx* resulted in higher percentages of galls. There was a high positive correlation between capsule destruction and *Smicronyx* densities (R^2 = 0.64). Control practices lowering the number of emerged *S. hermonthica* could increase the densities of

Smicronyx per *Striga* shoot. Such an increase of the number of *Smicronyx* per *Striga* shoot should augment the percentage of *Striga* seed-capsules galled and hence would contribute to the successful integrated control of *S. hermonthica*. Bashir (1987) reported that in smallholding farms of Southern Darfur (Sudan) where hand pulling of *Striga* plants before they flower was practiced, exceptionally high numbers of the adult weevils (15 to 25 per plant) were observed on the plants. Our finding that there is a high positive correlation between seed-pod galling and *Smicronyx* densities is relevant to biological control of *S. hermonthica* using augmentative techniques.

Our results differ from those obtained by Jost *et al.* (1996) in Northern Ghana. These authors reported that 17.4% of capsules produced were galled by *Smicronyx spp.* and that galls were found on 22.5% of shoots, resulting in a mean infestation (i.e. number of seed capsules per *Striga* plant transformed into galls) of 77.3%. Such a record suggests that *Smicronyx* female oviposition is grouped on few shoots. In contrast, the mean infestation (i.e. number of seed capsules per *Striga* plant transformed into galls) (9 to 25%) in each of our six fields were close to the percentage of capsules attacked in these fields (6.4 to 24.3%). The higher percentages of shoots bearing galls indicate that female *Smicronyx* tend to disperse their eggs among different *Striga* shoots in the field.

The statistical relationship between the fields and the densities indicates that the effectiveness of *Smicronyx* in seed-pod galling varied depending upon the fields, as suggested by the variation in the ratios, numbers of seed-pod galls/numbers of *Smicronyx* that ranged from 6 to 16 (Table 1). For instance, galling of the stems at soil level was more prevalent in field 3 (28 % of shoots affected) than in any others fields. Stem galling at soil level affects the growth and the reproduction of the entire shoot and hence increases the potential of *Smicronyx* as biocontrol agents. This variable selection of oviposition sites exhibited by the weevils could explain the relationship between the fields and the densities. Khan and Murthy (1955), Sankaran and Rao (1966) reported that *Smicronyx albovariegatus* galls the seed pods, the stems and the "root area" of *Striga asiatica* in India.

The ratios number of seed-pod galls/number of *Smicronyx* (6 to 16) suggest rates of reproduction of 12 to 32 larvae/female in seed-pods, assuming that the sex ratio is 50/50, without regard to the mortality of eggs, larvae and the galling of stems. This reproduction represents 50 to 100% of *S. hermonthica* shoot average capsule production i.e. 24 seed capsules in the field. This result agrees with those of Jost *et al.*(1996) who reported 14 galls (*i.e.* 14 larvae) per female *Smicronyx* in a pot experiment conducted in Northern Ghana and with the suggestion that seed-pod galling should be used in conjunction with other control methods to significantly deplete *S. hermonthica* seed production (Smith and Webb, 1996). Our data suggest that an increase of *Smicronyx* population levels up to three females per shoot, if used as part of an integrated control program, could significantly deplete *S. hermonthica* seed production.

Conclusion

The potential of *S. umbrinus* and *S. guineanus* as biocontrol agents of *S. hermonthica* is appreciable as suggested by their reproductive success on *S. hermonthica* and the fact that the weevils galled *S. aspera* capsules in fallow fields as well as *S. hermonthica* stems at soil level (preventing flowering). High population levels of *Smicronyx* resulted in higher percentages of attacked capsules although the weevil adult populations decreased during *S. hermonthica* capsule production. However seed-pod capsule galling alone is not sufficiently high in natural conditions to be considered a successful seed reduction factor. Nonetheless, biocontrol of *S. hermonthica* by augmentative techniques as part of an integrated control could be worthwhile strategy. Smith and Webb (1996) found that *Sm. umbrinus* needs to destroy 70 to 80% (instead of 95% as previously estimated by Smith *et al.*1993) of seed capsules each year to reduce the emergence of *S. hermonthica* by 50%. In conjunction to crop rotation, 22% of capsule destruction could achieve the same result in four or five years (Smith et *al.*,1993). Our results indicate that a population of two to three female *Smicronyx* per *Striga* shoot could significantly deplete *S. hermonthica* capsule production.

References

Bashir, M. O. 1987. The potential for biological control of Witchweeds. In Parasitic Weeds in Agriculture. Vol. 1: *Striga*. L. J. MUSSELMAN (Ed.), CRC Press Inc, p.183-206.

Berner, D. K., J.G. Kling, and B. B. Singh 1995. *Striga* Research and Control, a perspective from Africa. Plant Disease 79: pp. 652-657.

Cardwell, K. F., J. Smith, G. Weber, and A. Awad 1991. Framework for orientation of *Striga* research at IITA. Proc. 5th Int. Symp. Par. weeds. Nairobi, Kenya. Ransom *et al.* (Eds) CIMMYT, 503-511.

Combari, A. 1986. Contribution à l'étude de la germination et des moyens de lutte contre *S. hermonthica* et *S. gesnerioides*. Thèse de Docteur-Ingénieur. Institut National Polytechnique de Lorraine. Nancy I (France) 149 pp.

Doggett, H. 1988. Sorghum (2nd edition) p. 368-404. John Wiley & Sons, New York, N.Y.

Greathead, D. J. 1984. The natural enemies of *Striga* species and the prospects for their utilisation as biological control agents. In *Striga*: Biology and Control. E. S. AYENSU *et al.* (Eds). ICSU Press. Proc. Int. Workshop on the Biology an Control of *Striga*. Dakar, Sénégal, 133-160.

Greathead, D. J. and J. E. D. Milner 1971. A survey of *Striga spp.* (Scrophulariaceae) and their natural enemies in East Africa with a discussion on the possibilities of biological control.Trop. Agric. (Trinidad) **48**: 111-124.

Jayanth, K. P. 1988. Successful biological control of water hyacinth (*Eichhornia crassipes*) by *Neochetina eichhornia* (Coleoptera: Curculionidae) in Bangalore, India. Trop. Pest Man.34: 263-266.

Jost, A., J. Kroschel, and J. Sauerborn 1996. Studies on *Smicronyx spp.* and *Junonia orithya* and their potential for biological control of *Striga hermonthica* in Northern Ghana. In Advances in Parasitic Plant Research. Monero M. T., Cubero J.I. *et al.* Eds. Proc. 6th Int. par. Weed Symp. Cordoba, Spain. p. 888-898.

Khan, M.Q and D. V. Murthy 1955. *Smicronyx albovariegatus* Faust (Coleoptera, curculionidae) on *Striga spp.* Ind. J. Entomol. 17: 362.

Lagoke, S.T.O, V. Parkison, and R. M. Agunbiade 1991. Parasitic weeds and control methods in Africa. In Combatting Striga in Africa. Kim S.K. (ed.) Proc. Int. Workshop organized by IITA, ICRISAT and IRDC. Ibadan, Nigeria, 3-14.

Markham, R. H. 1985. Possibilities for the biological control of *Striga* species in the Sahel. Mission Report. Permanent Interstate Committee for Drought Control in the Sahel. 20 pp.

Murthy, D. V. 1960. Insects attacking *Striga*. Nature, 187: 959.

Nikiéma, S. 1992. Conditions agro-écologiques d'infestation du sorgho par *Striga hermonthica* (Del.) Benth. en zone nord-soudanienne du Burkina Faso: cas de Linonghin. Mémoire de Diplôme d'Etudes Approfondies (D.E.A.) en sciences biologiques appliquées. Laboratoire de Botanique et de

Biologie Végétale, Faculté des Sciences et Techniques, Université de Ouagadougou, 68 p.

Parker, C. and C. R. Riches 1993. Parasitic weeds of the world: Biology and Control. CAB Int. Castlefield Press, Kettering, Northants, UK.

Pronier, I. and K. Letierce 1995. Etude de la biologie d' un insecte, ***Smicronyx*** (Coléoptère, Curculionidés) suscesptible d' être utilisé dans la lutte biologique en région tropicale africaine / Etude des perturbations provoquées par la présence de larves de ***Smicronyx*** (Curculionidés) sur la capsule de ***Striga*** (Scrophulariacées). Relations avec les travaux effectués dans le cadre d' une lutte biologique. Mémoire de Maîtrise. Université Picardie Jules Verne, Amiens, France, 99 p.

Sankaran,T. and V. P. Rao 1966. Insects attacking witchweed (*Striga*) in India. Tech. Bull. Commonw. Inst. Biol. Control 7: 63-73.

Sauerborn, J. 1991. The economic importance of the phytoparasites ***Orobanche*** and ***Striga***. In: Proc. V Int. Symp. par. weeds, (J. K. Ransom, L. J. Musselman, A. D. Worksham and C. Parker, Eds.) pp 137-143 CYMMT, Nairobi, Kenya.

Smith, M.C., J. Holt, and M. Weeb 1993. Population model of the Parasitic weed ***Striga hermonthica*** (Scrophulariaceae) to investigate the potential of ***Smicronyx*** *umbrinus* (Coleoptera: Curculionidae) for biological control in Mali. Crop Protection 12: 470-476.

Smith, M. C and M. Webb 1996. Estimation of the seed bank of *Striga spp.* (Scrophulariaceae) in Malian fields and the implications for a model of biocontrol of *Striga hermonthica*. Weed Res., 36, 85-92.

Traoré, D., C. Vincent, and R. K. Stewart 1994. Dispersion pattern of adults and vertical distribution of larvae of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera: Curculionidae) on *Striga hermonthica* (Del.) Benth (Scrophulariaceae). Insect Sci. Applic. 15: 479-485.

Traoré, D. 1995. Bionomics of *Smicronyx guineanus Voss* and *Smicronyx. umbrinus* Hustache (Coleoptera: Curculionidae), potential biocontrol agents of *Striga hermonthica* (Del.) Benth. (Scrophulariaceae) Ph. D. Thesis, McGill University, Montreal, 205 p.

Traoré, D., C. Vincent, and R. K. Stewart 1996a. Association and Synchrony of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera: Curculionidae) and the parasitic weed *Striga hermonthica* (Del.) Benth (Scrophulariaceae). Biological Control, 7: 307-315.

Traoré, D., C. Vincent, and R. K. Stewart 1996b. Effects of precipitation on emergence of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera, Curculionidae) adults and soil vertical distribution of pupae. Int. J. Pest Man. 42: 9-12.

Williams, C. N. and G. H. Caswell 1959. An insect attacking *Striga*. Nature, 184: 1668.

Table 1: Impact of adult *Smicronyx* population levels on *S. hermonthica* capsule production in six farmers fields in Burkina Faso (N = 250 *Striga* shoots per field).

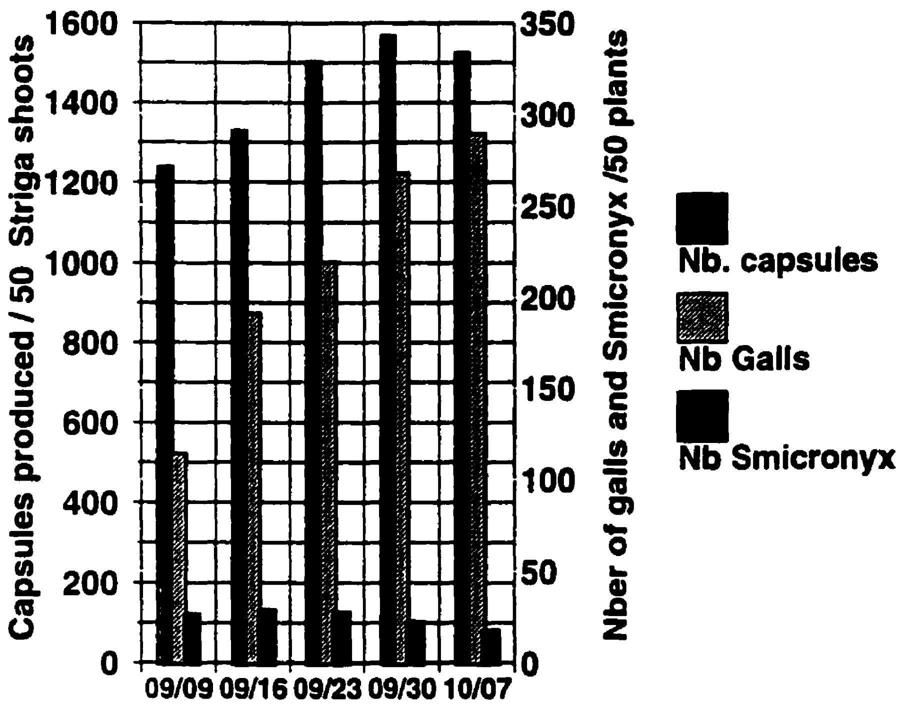
Fields	1	2	3	4	5	6
Total number of adult *Sm.**	40	116	178	108	108	86
Mean number *Sm.*/ shoot	0.16	0.46	0.71	0.43	0.43	0.34
Nb seed-pod galls	455	1345	1075	1240	1125	1385
% of galled seed-pods	6.4	17	24.3	18	19.5	20
%galls/*Sm.*/shoot	40	37	34	42	45	58
Galls/ *Smicronyx* **	11	12	6	11.5	10.4	16
Galls/female ***	22	24	12	23	21	32

* *Sm.* = *Smicronyx.*

** Galls/*Smicronyx* = average number of seed-pod galled per *Smicronyx* adult.

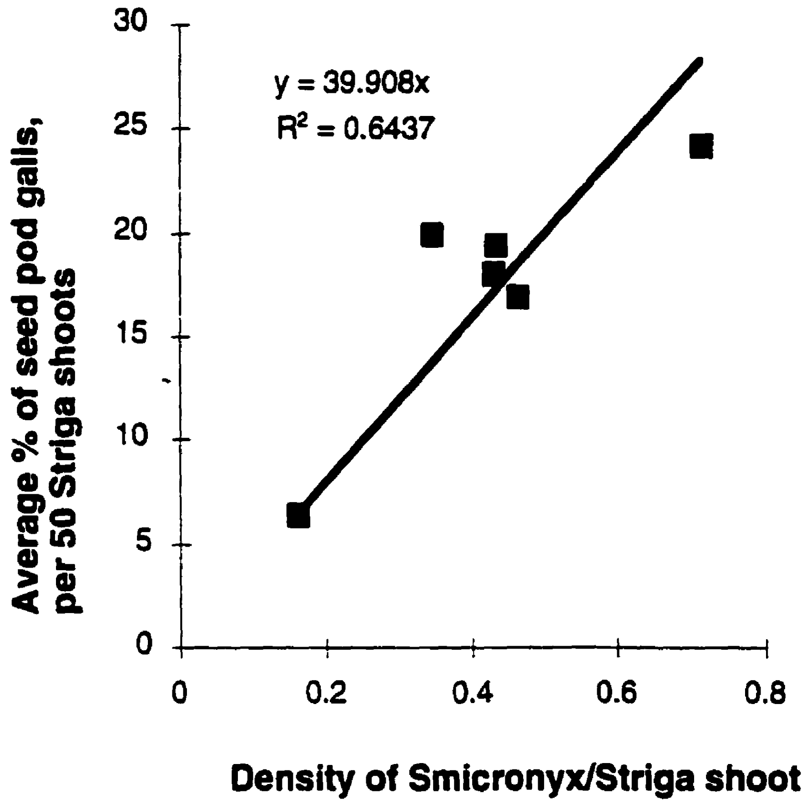
*** Assuming that the sex ratio is 50:50, each female *Smicronyx* galled 12 to 32 seed-pods.

Fig 1: Pattern of *S. hermonthica* capsule production, gall emergence and *Smicronyx* adult population in six farmers' fields in West Burkina Faso, 1996.



1600
1400
1200
1000
800
600
400
200
0
Capsules produced / 50 Striga shoots
350
300
250
200
150
100
50
0
Nber of galls and Smicronyx /50 plants
09/09
09/16
09/23
09/30
10/07
Nb. capsules
Nb Galls
Nb Smicronyx

Fig 2: Relationship between adult *Smicronyx* populations and *S. hermonthica* capsule galling.



y = 39.908x
R² = 0.6437
Average % of seed pod galls, per 50 Striga shoots
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
Density of Smicronyx/Striga shoot

Connecting statement

In chapter 1, the potential of *Smicronyx* spp. to control *Striga* spp. has been investigated on the basis of the percentage of seed-pods they gall in the course of *Striga* seed production. The evidence that seed-pod galling alone is not sufficiently high in natural conditions to be considered a successful reduction factor although significative seed production can be depleted suggests that to be effective biological control agents, *Smicronyx* spp. must completly prevent seed production. Gall inducers' ability to damage their host relates to the power of their galls as nutrient sinks (Harris and Shorthouse, 1996). *Smicronyx spp.* galls induced on others parts of *S. hermonthica* may be more efficient in diverting nutrients than are fruit galls and hence increase their impact on the overall seed production of the witchweeds. In addition, if *Smicronyx spp.* attack other important economic parasitic weeds, their importance as profitable biocontrol agents will be increased. Chapter 3 reports stem galls on *S. hermonthica* and *Alectra vogelii* Benth and estimates their impact on these parasitic weeds.

Chapter II *Smicronyx spp*. (Coleoptera: Curculionidae) stem galls on *Striga hermonthica* (Del.) Benth and *Alectra vogelii* Benth (witchweeds) in Burkina Faso (West Africa)

To be submitted to Insect Science and its Application.

Authors: L. C. **Otoidobiga, C. Vincent, R. K. Stewart, and J. Paré**

Abstract

Striga hermonthica (Del.) Benth and *Alectra vogelii* Benth (Scrophulariaceae) are obligate parasitic weeds that cause severe crop losses estimated at 3 to 7 billion $US per year in Africa south of the Sahara. Integrated control methods including biological control agents that will maintain these parasitic weeds under the economic threshold level are examined. In September 1996 in Burkina Faso, *Smicronyx spp.* were observed galling *S. hermonthica* and *A. vogelii* stems in addition to fruit galling previously reported on *S. hermonthica*. Sampling was carried out using a one m^2 quadrat in farmers' fields to investigate the frequency of these stem galls. The galls were described in the laboratory, and their impact on growth and seed production was statistically analyzed. Ninety five percent of *A. vogelii* and 20% of *S. hermonthica* shoots were galled. The stem galls were aggregates of several single galls fused together, often containing up to 19 or 28 larvae resulting from several oviposition attempts in the stem. Unattacked shoots were significantly longer and had more capsules and more flowers than attacked shoots. Of *S. hermonthica* and *A. vogelii* attacked seed-capsules, only those of *S. hermonthica* were often transformed into galls. Stem galls increase the potential of *Smicronyx spp.* to control *S. hermonthica* and *A. vogelii*.

Introduction

Witchweeds, *Striga hermonthica* (Del.) Benth and *Alectra vogelii* Benth (Scrophulariaceae), are parasitic weeds of cereal and leguminous crops in Africa south of the Sahara (Sallé and Raynal-Roques, 1989; Bagnall *et al.,* 1991). *S. hermonthica* parasitizes a wide range of cultivated plants, including corn (*Zea mays L.*), sorghum (*Sorghum bicolor* L.), rice (*Oryza spp.*), millet (*Pennisetum typhoides* L.) and peanut (*Arachis hypogea* L.). Losses of crop yield due to *S. hermonthica* in Africa are estimated from 3 to 7 billions $US per year (Sauerborn, 1991; Mboob, 1986). Although many control methods have been researched and developed against *S. hermonthica,* they have not been adopted to any appreciable extent by farmers because they are not economically affordable at the small holder level (Sieqfried, 1994).

A. vogelii parasitizes leguminous crops such as cowpea (*Vigna anguiculata* L.) and peanut. The yield of these crops is low (i.e.100 to 200 kg/ha) (Singh and Emechebe, 1991) partly because they are parasitized by *A. vogelii.* Such low yields do not provide enough income to enable farmers to use herbicides and fertilizers. Infestation of cowpea and peanut by *A. vogelii* has recently become very heavy in Africa i.e. 8 *Alectra* shoots/peanut plant (Salako, 1984), while no economically control method affordable to small farm holders is yet available.

Integrated control, including biological control agents that become established in the environment, is desirable (Cardwell *et al.,* 1991). *Smicronyx* weevils species offer a great potential for augmentative control programs (Parker and Riches, 1993; Greathead, 1984; Traoré *et al.,* 1996). They have a narrow host range, and the timing of their life cycle is well synchronized with those of their hosts *Striga* species (Traoré *et al.,* 1996).

It is generally stated in the scientific literature that West African *Smicronyx* species usually gall only the fruits of *Striga spp.* (Williams and Caswell, 1959; Traoré, 1995). Smith and Webb (1996) using mathematical models to investigate the potential of *Smicronyx umbrinus* Hustache seed-pod galling to deplete *S. hermonthica* seed production, suggested that heavy (70-80%) capsule galling is required each year without failure to result in 50% *S. hermonthica* eradication. Nonetheless, data on the impact of *Smicronyx spp.* on *S. hermonthica* are still fragmentary. Anderson and Cox (1997) mentioned stem galls due to *Smicronyx umbrinus* Hustache and *Sm. guineanus* respectively on *S. hermonthica* at soil level in Niger, and due to *Sm. dorsomaculatus* on *Striga gesnerioides* (Willd) Vatke in Burkina Faso. In 1996, we observed that *Smicronyx spp.* gall any part of the stems of *A. vogelii* while those of *S. hermonthica* are only galled at soil level. Stem galling may have greater impact than seed-pod galling on seed production as it could likely divert more nutrient from the entire plant and hence increase the potential of *Smicronyx* to control *S. hermonthica* and *A. vogelii*.

This paper 1) describes the galls, 2) reports their frequency in farmers' fields, and 3) reports their impact on the growth and seed production of *S. hermonthica* and *A. vogelii*. To achieve these objectives, the parasitic weeds were sampled in farmers' fields in Burkina Faso and observed in the laboratory.

Materials and methods

Stem galls of *A. vogelii*

Sampling was carried out in September 1996 in two farmers fields (2-3 ha) to assess infestation by *A. vogelii* at Toussiana (55 km West of Bobo-Dioulasso), Burkina Faso. On three occasions, 10 one m^2 quadrats were randomly delimited in each field to record *A. vogelii* plants galled by *Smicronyx*. *A. vogelii* harvested from five one m^2 quadrats were brought back to the laboratory where they were visually assigned to three classes, namely 1) shoots at the maturing capsule stage bearing no stem galls, 2) shoots at the maturing capsule stage bearing stem galls, and 3) young shoots bearing stem galls. Fifty shoots of each class (i.e. a total of 155) were observed and the following parameters were recorded: 1) the height of the shoots, 2) the number of stems/shoot, 3) the number of flowers/shoot, 4) the number of capsules/shoot, 5) the number of galls/shoot, 6) the number of larvae/gall.

A Multiple Factorial Analysis of Variance (ANOVA, SAS General Linear Model Procedure, SAS Institute Inc., 1989) and Student Newman-Keuls test ($p < 0.05$, $n = 155$) were performed to estimate the impact of the stem galls on *A. vogelii* growth and seed production.

Stem galls of *Striga hermonthica*

S. hermonthica were sampled using the methodology described above for *A. vogelii*. Sampling was done in September 1996 in two farmers' fields (1.5-2 ha) at Matourkou (15 km West of Bobo-Dioulasso) Burkina Faso, West Africa. The same variables recorded for *A. vogelii* were recorded and the same analysis performed (ANOVA, $p < 0.05$; $n = 221$).

Voucher specimens of adult *Smicronyx* and larvae in seed-pods and stem galls were deposited at the Systematic Entomology Laboratory, USDA, National Museum of Natural History, Washington, D. C., USA. *Smicronyx* specimens were also deposited at the Biosystematics Research Center (Agriculture Canada) Ottawa, Canada. Galled *A. vogelii* plants were deposited at the Museum National d'Histoire Naturelle de Paris, France.

Results

Smicronyx* species attacking *A. vogelii

A mean number of 19 *A. vogelii* plants per m^2 quadrat were recorded in field 1, (min: 2, max: 42). In field 2 we recorded a mean number of 4 shoots per m^2 (Min: 1 max: 11). *Smicronyx dorsomaculatus*, *Smicronyx guineanus* and a *Smicronyx n. sp.* not yet described were observed on the shoots. The new species is being described by Donald. M. Anderson, Systematic Entomology Laboratory, USDA, Washington, DC. On September 11, 1996, 81% of *A. vogelii* plants were galled in field 1, and 85% in field 2. On September 18, ca. 95 to 100% of the plants were galled in both fields. All stem galls showed *Smicronyx spp.* larvae. In a sample of 57 larvae, 41 (72%) were *Sm. dorsomaculatus*, ten (18%) were *Smicronyx n. sp* and six (10%) were *S. guineanus* Voss.

The shoots at the maturing capsule stage bearing no stem galls on average had five stems 29 cm long, and produced 15 flowers and five capsules each. Those at the maturing capsule stage bearing stem galls had on average 11 cm long, three stems and produced one capsule each. Seedling shoots were entirely transformed into galls reaching ca 4 cm long (Table 2). When the full grown larvae left the galls to pupate in the soil, the galls decayed and the attacked shoots completely desiccated.

The stem galls were aggregates of several single galls fused together. We observed up to 19 larvae in plurilocular gall cavities (Fig. 3). Young shoots generally bore one such large gall (3 cm in length, 1.5 cm in wide: Fig. 4) that resulted from an hypertrophy of the meristem tissues of the stems. As a consequence, the growth of the young attacked shoots was inhibited. Before the larvae matured, open wounds (from hypertrophy) were healing on the galls. Older shoots bore up to 11 galls. Twenty eight out of 504 (6%) *A.vogelii* capsules were attacked. In contrast to *S. hermonthica* capsule galls, no attacked *A. vogelii* capsules were transformed into galls.

There were significantly more capsules (5) and more flowers (15) on unattacked *A.vogelii* than on the attacked shoots (1capsule and 4 flowers) and the unattacked shoots were significantly higher (29 cm) than attacked shoots (11 cm) (P = 0.0001; n= 155). There was a significant statistical correlation between the number of galls and 1) the height of the plant 2) the number of flowers (P = 0.0001; n= 155).

Smicronyx* species attacking *S. hermonthica

The mean densities of *S. hermonthica* were respectively 17 and 38 shoots per m^2 quadrat in field 1 and 2. Both *Smicronyx guineanus* Voss and *Sm. umbrinus* Hustache adults were observed on *S. hermonthica* shoots. All stem galls showed *Smicronyx spp.* larvae. Seventy out of 80 larvae (88%) were *S. umbrinus* Hustache and ten (12%) were *Smicronyx guineanus* Voss. Twenty per cent of shoots showed stem galls by September 23. Young *S. hermonthica* were the most attacked (28%). Older *Striga* shoots were less galled (15%), which lowered the overall percentage of galled shoots in the entire population of the witchweed. In contrast to *A.vogelii* stem galls upper location, the stem galls of *S. hermonthica* were hidden in the soil so that stunting *Striga* shoots suffering from this symptom could be confused with others suffering from *Fusarium* diseases.

At the maturing capsule stage as on *A. vogelii,* the unattacked shoots were higher (67cm), and produced more capsules (22) than attacked shoots (37 cm high and 3.2 capsules). The attacked older shoots at the maturing capsule stage were stunted. The young attacked shoots rarely flowered (Table 2). In contrast to the stem galls of *A.vogelii,* the stem galls of *S. hermonthica* did not rot but the attacked shoots desiccated after the full grown larvae had left the galls.

As on *A. vogelii, S. hermonthica* stem galls were multilocular aggregates of several single galls fused together (Fig 5). They were smaller than those on *A. vogelii* (on average 1 cm length, 0.8 cm wide) but contained approximately the same number of larvae (mean number 4, max: 23), each larva being located in a separate cavity. The highest number of larvae in a gall (n = 23) was recorded on a young shoot. Full grown larvae totally destroyed the tissues, preventing sap flow.

Attacked shoots at the maturing capsule stage bore three types of galls i.e. 1) stem galls at soil level (20% in the fields), 2) attacked capsules transformed into galls (18%, n = 1428) and 3) attacked capsules not transformed into galls but containing full grown larvae (9%, n = 1428). Attacked fruit, whether transformed into galls or not, generally contained only one single larva, occasionally two larvae. Few if any seeds were left in the attacked capsules containing full grown larvae.

There were significantly more capsules and more flowers on unattacked than on the attacked shoots and the unattacked shoots were significantly higher. There was a significant statistical correlation between the stem galls and 1) the height of the plant, 2) the number of stems, and 3) the number of flowers ($p = 0.0001$; $n = 221$).

Discussion

Gall inducers are favored as biocontrol agents because they tend to have a narrow host range and hence threaten few non-target hosts (Harris and Shorthouse, 1996). To be successful, they must, as any biocontrol agent, reduce the target weed over much of its geographical range by reducing survival, growth, or reproduction. Gall formers achieving this successful control induce powerful galls that divert assimilates from other sinks via their vascular system joined to that of their host (Harris and Shorthouse, 1996). Gall inducers are cited among the most successful biocontrol agents in the world *i.e* the control of *Carduus nutans* with

Rhinocyllus conicus Froel (Coleoptera: Curculionidae) in Canada (Crawley, 1989), and those of *Acacia longifolia* by *Trichilogaster acaciaelongifoliae* Froggatt (Hymenoptera: Pteromalidae) in South Africa (Dennill, 1988). Fecundity, ecological range, susceptibility to parasitism and the harm caused to the hosts are known to influence the potential of biocontrol agents. Here we discuss the harm the stem galls of *Smicronyx spp.* caused to *A. vogelii* and *S. hermonthica* in light of their effect as nutrient sinks expressed by the reduction of the survival, the growth, and the reproduction of the attacked shoots.

Smicronyx species attacking *A. vogelii*

This is the first report of *Smicronyx spp.* galling *A. vogelii*. The galls are much like those of *S. gesnerioides* due to *Sm. dorsomaculatus* (D. M. Anderson, personal communication). The morphology of the galls suggests that they were formed by larvae resulting from several oviposition attempts on the stem. The stem, flower and capsule production of the attacked older *A. vogelii* shoots were lower than those of unattacked shoots while the growth of the young attacked shoots was completely inhibited, expressing diversion of nutrients from all parts of the plant for the profit of stem galls. The major problem arising for the host plant from such nutrient diversion is that plant tissues subjected to such severe damage may die.

The healing of the open wounds before the maturation of the larvae, could be a reaction of the host which produces indoleacetic acid in response to damage from enzymes produced by gall inducers (Alexander, 1987), or a strategy of larvae that maintain the host alive for their required life time in its tissues by causing it to produce high level of cytokinin in the gall (Hewett, 1977). Cytokinin has a strong nutrient-sink and anti-senescence activity by increasing nutrients in the gall and delaying its senescence to the detriment of ungalled tissues (Harris and Shorthouse, 1996).

The attacks progressed rapidly. Respectively 15 to 20% of the parasitic weeds developed galls from 11 to 18 September 1996 in fields infested on average by 19 and 4 *A. vogelii* per m^2 quadrat. The high percentage (95-100%) of attacks in the fields, the large number of larvae in galls (up to 19 in a gall) and the percentage of *Sm. dorsomaculatus* larvae in the galls (71%) suggest that this species has a high reproductive success on *A. vogelii.* McFadyen and McClay (1981) reported a mean daily egg production of 3.23 (max 14) and a mean total egg production of 237.13 per female (max 411) of *Smicronyx lutulentus* on *Parthenium hysterophorus*. In contrast to *S. hermonthica,* in which both capsules and stems were transformed into galls, few (6%) *A. vogelii* capsules were attacked and were not transformed into galls.

The statistical correlation between the height of the shoots and the galls for capsule and flower production indicates that the impact of the galls is dependent on the stage at which the shoots were attacked. Attacks on older shoots resulted respectively in 73 and 80% of decrease of their flower and capsule production while young attacked shoots desiccate without producing either stems, or flowers. All emerging *A. vogelii* young shoots were galled by September 23. The galls rotted and the parasitic weed died after the full grown larvae emerged by several holes to pupate in the soil. The excavation of these holes through the wall of the gall may destroy the phloem and the xylem, causing the decay of the shoot. The number of stems was not diminished on the older shoots bearing galls because on these shoots numerous stunted stems often grow from the top of the gall as a reaction of the plant to the attack. These stunted stems produced no seed-capsules. On average, seed production is reduced by 80% on older attacked shoots, while there is no seed production when the attack occurs on seedling shoots (Table 2). These data suggest that *Smicronyx spp.* can reduce *A. vogeli* over much of its geographical range as they reduce its survival, growth, and reproduction. We recommend further investigations to assess the possibility of introduction, conservation and augmentation of these *Smicronyx* species in the geographical areas where *A. vogelii* is becoming a major threat to leguminous crops in Africa.

Smicronyx **spp. attacking** ***S. hermonthica***

Our work is the first to assess the impact of stem galls due to *Smicronyx* on *S. hermonthica* growth and capsule production. We observed stem galls at soil level in September 9. As for *A. vogelii* stem galls, the power of *S. hermonthica* stem galls as nutrient sinks was expressed by a decrease in: 1) the height of attacked shoots (45% less than unattacked shoots), 2) the reproduction rate (85% fewer capsules), and 3) the death of the attacked young shoots before production of seed capsules (Table 1). However, the percentages of stem galls, 20% (in fields infested on average by 17 and 38 shoots/m^2 quadrat) was low compared to those observed on *A. vogelii* (95-100% in fields infested on average by 4 and 19 shoots/m^2 quadrat). Khan and Murthy (1955), Sankaran and Rao (1966) reported that *Smicronyx albovariegatus* galls the seed pods, the stems and the "root area" of *Striga asiatica* in India. Such variable selection of oviposition sites by *Smicronyx spp.* could explain the lower percentage of stem galls on *S. hermonthica*.

The statistical interaction between the stem galls and 1) the height of the shoot and 2) the number of flowers indicates that attack on older shoots results in a reduction of up to 85% of their flower and capsule production. These results differ from those of Rao and Sankaran (1966), who observed no reduction of growth and/or seed production of *S. asiatica* attacked at every level (roots, stem and fruits) by *Smicronyx albovariegatus* in India. McFadyen and McClay (1981) reported that from hatching to full grown larvae, *Smicronyx lutulentus* larvae spend 21 days in their host tissues. After emergence *S. hermonthica* plants flower in ca. 21 days. Young shoots dying without producing any fruit suggest that *Smicronyx umbrinus* larvae destroyed the phloem and the xylem causing their desiccation within 21 days and that these young shoots were attacked at their very early emerging stage while older attacked shoots bearing mature capsules may have been attacked when they were already flowering.

Attacked fruit not transformed into galls could not be distinguished from unattacked ones until after dissection of the fruits. Why *Smicronyx spp.* attack does not always induce *Striga* seed-pod galls is unknown. Ungalled seed-pods containing full grown larvae may have been attacked by female weevils after reaching a state where they could not grow any further but were still tender enough to be penetrated.

Seed-pod galls reduced the quantity of seeds added to the soil but had little impact on the average height of the shoot, the number of stems, the number of flowers and capsules produced. Infestation levels of individual plants were variable and the number of seed-pods galled per plant ranged from 1 to 15 and depended on the size and age of the plant. In another survey, we recorded a shoot bearing 41 galls of 59 capsules to be galled. In general, large vigorous plants were more heavily galled. These results are similar to those recorded by Greathead and Milner (1971) in Uganda.

Conclusion

Smicronyx dorsomaculatus, Sm. guineanus and *Smicronyx sp.* attacked 95% of *A. vogelii* in the field, killing young shoots and diminishing the growth and seed production of older attacked shoots. The weevils attacked few (6%) *A. vogelii* seed-pods and these attacked seed-pods were not transformed into galls. Seventy-two per cent of the larvae forming stem galls were *Sm. dorsomaculatus*.

S. umbrinus and *S. guineanus* caused stem galls at soil level on 20% *S. hermonthica*. The attacked shoots stunted and desiccated as a consequence of the diversion of nutrients and destruction of xylem and phloem in stems. Eighty eight per cent of *S. hermonthica* stem galls were *Sm. umbrinus*. *Sm. umbrinus* and *Sm. guineanus* also attacked *S. hermonthica* seed-pod capsules. Nine per cent out of 26.7% (n = 1428) of attacked capsules were not transformed into galls.

Our results indicate that, in addition to the often cited impact on capsules (Williams and Caswell, 1959; Traoré, 1995), *Smicronyx* attack lower parts of the *Striga* plant. Further studies of the biology and host specificity of *Sm. dorsomaculatus* and *Sm. umbrinus* are recommended to investigate the extent at which these species could be introduced, conserved or their populations increased in areas affected by *A. vogelii* and *S. hermonthica*.

References

Alexander, A. 1987. Compatibility of Picloram and the Tephritid Fly *Uphora cardui* for Canada Thistle (*Cirsium arvense* L.) control. M. Sc. Thesis, University of Saskatchewan, Saskatoon, SK, 95p.

Anderson, D. M., and M. L. Cox 1997. *Smicronyx* species (Coleoptera: Curculionidae) economically important as seed predators of Witchweeds (*Striga* spp.) (Scrophulariaceae) in Sub-Saharan Africa. Bull. Entom. Res. 87: 3-17.

Bagnall-Oakeley, H., V. Gibberd, and T. E. Nyongesa 1991. The incidence and control of *Alectra vogelii* in Embu District. Proc. 5th int. Symp. Par. Weeds, Nairobi, Kenya; Ransom *et al.*(eds) pp. 340-345.

Cardwell, K.F., J. Smith, G. Weber, and A. Awad 1991. Framework for orientation of *Striga* research at IITA. Proc. 5th Int. Symp. Par. weeds. Nairobi, Kenya. Ransom *et al.* (Eds.) CIMMYT, 503-511.

Crawley, M.J. 1989. The successes and failures of weed biocontrol using insects. Biocontrol News and information 10: 213-223.

Dennill, G.B. 1988. Why a gall former can be a good biocontrol agent: the gall wasp *Trichilogaster acaciaelongifoliae* and the weed *Acacia longifolia*. Ecol. Entomol 13: 1-9.

Greathead, D. J. 1984. The natural enemies of *Striga* spp. and the prospect for their utilisation as biological control agents. In: *Striga* Biology and Control (E. S. Ayenu, *et al.* eds.) I.C.S.U., Paris, pp 133-160.

Harris, P. and J.D. Shorthouse 1996. Effectiveness of gall inducers in weed biological control. Can. Entomol. 128: 1021-1055.

Hewett, E.W. 1977. Some effect of infestation on plants: A physiological view point. New Z. Entomol. 6: 235-243.

Jayanth, K. P. 1988. Successful biological control of water hyacinth (*Eichhornia crassipes*) by *Neochetina eichhornia* (Coleoptera, curculionidae) in Bangalore, India. Trop. Pest

Man. 34: 263-266.

Khan, M.Q. and D. V. Murphy 1955: *Smicronyx albovariegatus* Faust (Coleoptera, Curculionidae) on *Striga spp.* Indian J. Entomol, 17: 362.

Mboob, S. S. 1986. A regional program for *Striga* control in West and Central Africa. In: Improved Management in Africa: Proc. of the FAO/OAU ALL Africa Government Consultation on Striga control, pp. 191-194, Maroua, Cameroun.

McFadyen, R.E. and A.S. McClay 1981. Two new insects for the biological control of Parthenium weed in Queensland. Proc. VI Australian weed conf., Gold Coast, Queensland, p. 145-149.

Parker, C. and C. R. Riches 1993. Parasitic weeds of the world: Biology and Control. CAB Int. Castlefield Press, Kettering, Northants, UK.

Sankaran, T. and V. P. Rao 1966. Insects attacking witchweed (Striga) in India. Tech Bull. Commonw. Inst. Biol. Control 7: 63-73.

Sallé, G. and A. Raynal-Roques 1989. Le *Striga*. La Recherche. 206: 44-52.

Salako, E. A. 1984. Observations on the effect of *Alectra vogelii* infestation on the yield of groundnut. Trop. Pest Man. 30: 209-211.

Sauerborn, J. 1991. The economic importance of the phytoparasites *Orobanche* and *Striga*. In: Proc. V Int. Symp. par. weeds, CYMMT, Nairobi, Kenya pp 137-143. J. K. Ransom, *et al.* Eds.

Siegfried, K. D. 1994. Socio-economic constraints to the adoption of weed control techniques: the case of *Striga* control in the West African Semi-Arid Tropics. Int. J. Pest Man.40 (2) 153-158

Singh, B. B. and A.M. Emechebe 1991. Breeding for resistance to *Striga* and *Alectra* in cowpea. Proc. 5th int. Symp. Par. Weeds, Nairobi, Kenya; Ransom *et al.*(eds) pp 303-305.

Smith, M.C., J. Holt, and M. Webb 1993. Population model of the Parasitic weed *Striga hermonthica* (Scrophulariaceae) to investigate the potential of *Smicronyx umbrinus* (Coleoptera: Curculionidae) for biological control in Mali. Crop Protection, 12: 470-476.

Smith, M. C. and M. Webb 1996. Estimation of the seed bank of *Striga spp.* (Scrophulariaceae) in Malian fields and the implications for a model of biocontrol of *Striga hermonthica*. Weed Res. 36, 85-92.

Traoré, D. 1995. Bionomics of *Smicronyx guineanus Voss* and *Smicronyx. umbrinus* Hustache (Coleoptera: Curculionidae), Potential biocontrol agents of *Striga hermonthica* (Del.) Benth. (Scrophulariaceae) Ph. D. Thesis, McGill University, Montreal, 205 p.

Traoré, D., C. Vincent, and R. K. Stewart 1996. Association and Synchrony of *Smicronyx guineanus* Voss, *S. umbrinus* Hustache (Coleoptera: curculionidae) and the Parasitic Weed *Striga hermonthica* (Del) Benth. (Scrophulariaceae). Biol. Control 7, 307-315

Williams, C. N. and G. H. Caswell 1959. An insect attacking *Striga*. Nature, **184**: 1668.

Table 2: Impact of *Smicronyx spp.* stem galls on *S. hermonthica* and *A. vogelii* growth and capsule production.

	Older shoots		Young shoot	SNK p<0.05
	Unattacked	Attacked	Attacked	
A) ***Striga hermonthica*** (N = 221).				
Average height of shoots (cm)	67	37	21	***
Mean number of Flowers/shoot	31	9.5	6.5	***
Mean number of capsules/shoot	22	3.2	0.3	***
Mean number of Stems/shoot	7	7	3.5	ns
B) ***Alectra vogelii*** (N = 150).				
Average height of shoots (cm)	29	11	4	***
Mean number of flowers/shoot	15	4	0	***
Mean number of capsules/shoot	5	1	0	***
Mean number of stems/shoot	5	3	0	ns

ns = not significant.

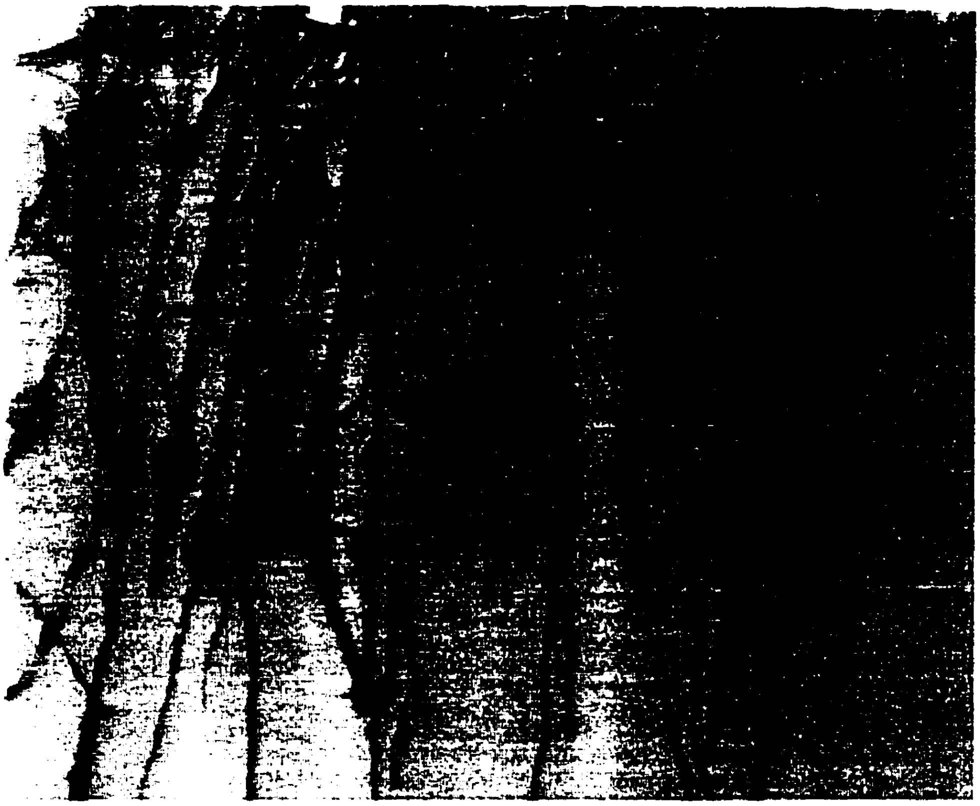
*** Highly significant (p = 0.0001)

NKS = Student and Newman-Keuls test.

Fig 3: *Smicronyx spp.* larvae in plurilocular gall cavities of *Alectra vogelii* Benth.

Fig 4: Young *Alectra vogelii* Benth shoots entirely transformed into large galls by *Smicronyx spp*, and showing open wounds from hypertrophy of the meristem.

Fig 5: Stem galls of *Striga hermonthica* (Del.) Benth at soil level due to *Smicronyx spp.*



General discussion and conclusion

Striga is considered as the single greatest biological constraint to food production in Africa, and its control remains essentially unsolved despite tremendous efforts brought by the international scientific and agronomic community through diverse research networks. One reason explaining this situation is that the various proposed control methods were proven not to be economically feasible at the small farm level in the African socio-economic context.

Integrated control strategies, including biological control agents that become established in the environment are now considered the approach that could likely succeed. Various potential biocontrol agents, mainly fungi and herbivorous insects, are being studied among which *Smicronyx spp.* are favored candidates. However data about the biology and the effectiveness of these candidates in the field are still fragmentary.

My research was undertaken to test the hypothesis that *Smicronyx* spp. seed-pod galling could substantially deplete *Striga hermonthica* capsule production in the field and hence contribute to bring this witchweed under control in an integrated control program framework. The results achieved indicated that high population levels of *Smicronyx* resulted in higher percentages of attacked capsules, but the percentages of capsules galled in the field in natural conditions (without conservation or augmentation) were not sufficiently high to consider seed-pod galling alone as a successful means to control *S. hermonthica*. Nonetheless, *Smicronyx spp.* were also observed galling *Alectra vogelii* and *S. hermonthica* stems, causing severe reduction of the growth and seed production of the attacked shoots. This new information indicates that *Smicronyx* spp. attacking *Striga* spp. should not be considered as seed-pod galling insects only. Sankaran and Rao (1966), observed that *Sm.*

albovariegatus galls the seed pods, the stems, and the root area of S. asiatica in India.

Stem galling of seedling *A. vogelii* and *S. hermonthica* occurs at their physiolosically most vulnerable stage and hence is most effective in controlling witchweeds. At a later stage, stem galling reduce or entirely prevent flowering and reproduction. These new informations indicate that it is worth to further investigate to wich extend such damages could be increased to augment *Smicronyx* spp. pressure on witchweeds.

In constrast to the impact of *Sm. albovariegatus* that was found negligible (Sankaran and Rao 1966), the impact of African indigenous *Smicronyx* spp. on *Striga* spp. is appreciable as supported by our results. Their potential to control witchweeds must be estimated on their overall impact on witchweed growth, flowering and reproduction, not on seed pod destruction only.

Biological control by mass rearing and repeated mass release of insects is hardly practicable due to the cost of the process (Bashir, 1987). However whatever witchweed control measures are eventually found affordable for African peasants, *Smicronyx* weevils will remain an important part of the natural resistance to witchweeds in Africa, and control by augmentative techniques as part of an integrated control could be profitable. My point is that projects conceived on a community based approach in which farmers learn how to preserve *Smicronyx* larvae could be less costly and more successful. This requires additional research to estimate the density of populations that shall provide satisfactory control in the context of farmers' usual practices, and a better knowledge of the ecology and behavior of the weevils.

References

Abbasher, A. A. and Sauerborn, J. 1992. *Fusarium nygami*, a potential bioherbicide for *Striga hermonthica* control in sorghum. Biol. Control 2: 291-296.

Abbasher, A.A., Hess, D.E. Sauerborn, And J. Kroschel 1996. Effect of different *Fusarium spp.* on seed germination of *Striga hermonthica* (Sorghum and millet strains), *S. asiatica* and *S. genesrioides.* In Advances in Parasitic plant research. Monero M.T., Cubero J.I. *et al.*, Eds. Proc. 6th Int. Par. Weed Symp. Cordoba, Spain. 879-887.

Alexander, A. 1987. Compatibility of Picloram and the Tephritid Fly *Uphora cardui* for Canada Thistle (*Cirsium arvense* L.) control. M. Sc. Thesis, University of Saskatchewan, Saskatoon, SK, 95p.

Anderson, D. M. and M. L. Cox 1997. *Smicronyx* species (Coleoptera: Curculionidae) economically important as seed predators of Witchweeds (*Striga* spp.) (Scrophulariaceae) in Sub-Saharan Africa. Bull. Entomol. Res. 87: 3-17.

Bagnall-Oakeley, H., Gibberd, V., and T.E. Nyongesa 1991. The incidence and control of *Alectra vogelii* in Embu District. Proc.5th int. Symp. Par. Weeds, Nairobi, Kenya; Ransom *et al.*(eds) pp. 340-345.

Bashir, M. O. and L. J. Musselman 1984. Some natural enemies of *Striga hermonthica* in the Sudan. Trop. Pest Man. 30, 211-212.

Bashir, M. O. 1987. The potential for biological control of Witchweeds. In Parasitic weeds in Agriculture. Vol. 1: *Striga*. L. J. MUSSELMAN (Ed.), CRC Press Inc, 183-206.

Bebawi, F. F. 1981. Intraspecific physiological variants of *Striga hermonthica*. Exp. Agric. 17:419

Berner D.K., Kling J.G., and B.B. Singh 1995. *Striga* Research and Control, a perspective from Africa. Plant Disease 79: pp. 652-657.

Butler, L. G. 1989. Striga scourge of African cereals; in INTSORMIL 89-1 (International Sorghum and Millet

Collaborative Research Support Program), University of Nebraska, Lincoln, NE 16 p.

Cardwell, K.F., Smith, J., Weber, G., and A. Awad 1991. Framework for orientation of *Striga* research at IITA. Proc. 5th Int. Symp. on Parasitic weeds. Nairobi, Kenya. Ransom *et al.* (Eds.) CIMMYT, 503-511.

Ciotola, M. , A. K. Waston, and S .G. Hallet 1993. The potential of using fongi for the biocontrol of witchweeds. 6th Int. Congr. Plant Path., Montreal, 1993.

Ciotola, M., Waston, A. K. and S. G. Hallet 1995. Discovery of an isolate of *Fusarium oxysporum* with potential to control *Striga hermonthica* in Africa. Weed Res. 35: 303-309.

Combari, A. 1986. Contribution à l'étude de la germination et des moyens de lutte contre *S. hermonthica* et *S. genesrioides*. Thèse de Docteur-Ingénieur. Institut National Polytechnique de Lorraine. Nancy I, France. 149 pp.

Crawley, M. J. 1989. The successes and failures of weed biocontrol using insects. Biocontrol News and information 10: 213-223.

Day, R. A. 1994. How to write and publish a scientific paper. 4th ed. Phoenix: Oryx press.

Dennill, G.B. 1988. Why a gall former can be a good biocontrol agent: the gall wasp *Trichilogaster acaciaelongifoliae* and the weed *Acacia longifolia*. Ecol. Entomol 13: 1-9.

Doggett, H. 1984. *Striga,* its biology and control, an overview. In *Striga*: Biology and control. E.S. Ayensu *et al.* (Eds) ICSU Press. Proc. Int. Workshop on the biology and control of *Striga*. Dakar, sénégal, P 27-36.

Doggett, H. 1988. Sorghum (2nd edition) p. 368-404. John Wiley & Sons, New York, N.Y.

Edwards, W.D.H. 1979. Orobanche and other plant parasite factors. pp.235-248. In: J.B. Harborne (ed.) Phytochemical Ecology. New York Academic Press.

Ejeta, G., Butler, L. G., and Babiker A. G. 1992. New approaches to the control of *Striga*. *Striga* research at

Purdue University. Agricultural Experiment Station. Purdue University. West Lafayette, IN.

Eplee, R. 1984. Chemical control of Striga. In: *Striga* biology and control. E. S. Ayenu *et al*. eds.) I.C.S.U., Paris, p 113-123.

Eplee, R. and M. Langston 1991. Integrated control methodology for *Striga* in the USA. Proc. 5th Int. Symp. Par. weeds, Ransom J. K. *et al* (eds), Nairobi, Kenya.

Gbehounou, A. 1996. Survie des graines de *Striga hermonthica* en milieu réel au Benin: Implication pour le choix des methodes de lutte. 4th General Workshop of the PASCON, Bamako, Mali, 1996.

Greathead, D. J. 1984. The natural enemies of *Striga* spp. and the prospect for their utilisation as biological control agents. In: *Striga* biology and control (E. S. Ayenu *et al*. eds.) I.C.S.U., Paris, p 133-160.

Greathead, D. J. and Milner J. E. D. 1971. A survey of Striga spp. (Scrophulariaceae) and their insect natural enemies in East Africa with a discussion on the possibilities of biological control. Trop. Agric., 48: 11-124.

Harris, P. and J.D. Shorthouse 1996. Effectiveness of gall inducers in weed biological control. Can. Entomol. 128: 1021-1055.

Hewett, E.W. 1977. Some effect of infestation on plants: A physiological view point. N. Z. Entomol. 6: 235-243.

Jayanth, K. P. 1988. Successful biological control of water hyacinth (*Eichhornia crassipes*) by *Neochetina eichhornia* (Coleoptera, Curculionidae) in Bangalore, India. Trop. Pest Man. 34: 263-266.

Jost, A., Kroschel, J., and J. Sauerborn 1996. Studies on *Smicronyx spp*. and *Junonia orithya* and their potential for biological control of *Striga hermonthica* in Northern Ghana. In advances in parasitic Plant Research. Monero M. T., Cubero J. I. *et al*. Eds. Proc. 6th Int. Par. Weed Symp. Cordoba, Spain, p. 888-898

Khan, M.Q and D.V. Murthy 1955. *Smicronyx albovariegatus* Faust (Coleoptera, Curculionidae) on *Striga spp.* Ind. J. Entomol. 17: 362.

Kirk, A. A. 1993. A fungal pathogen with potential for biocontrol of *S. hermonthica* (Scrophulariaceae). Entomophaga 38: 459-460.

Lagoke, S.T.O, Parkison, V. And R. M. Agunbiade 1991. Parasitic weeds and control methods in Africa. In combatting Striga in Africa. Kim S.K. (ed.) Proc. Int. Workshop organized by IITA, ICRISAT and IRDC. Ibadan, Nigeria, 3-14.

Lynn, D.G. and M.Chang 1990. Phenolic signals in cohabitation: implication for plant development. Ann. Rev. Plant Physiol. 41: 497-526..

Markham, R. H. 1985. Possibilities for the biological control of *Striga* species in the Sahel. Mission Report. Permanent Interstate Committee for Drought Control in the Sahel. 20 pp.

McFadyen, R.E. and A.S. McClay 1981. Two new insects for the biological control of Parthenium weed in Queensland. Proc. VI Australian Weed Conference, Gold Coast, Queensland, pp 145-149.

Mboob, S. S. 1986. A regional program for *Striga* control in West and Central Africa. In: Improved management in Africa: Proc. of the FAO/OAU All Africa Government Consultation on Striga control, pp. 191-194, Maroua, Cameroun.

Musselman, L.J. 1980. The biology of *Striga, Orobanche,* and other root parasitic weeds. Ann. Rev.Phytopathol. 18:463-489.

Musselman, L.J. and F.N. Hepper 1986. The witchweeds (*Striga,* Scrophulariaceae) of the Sudan Republic. Kew. Bull. 41:205.

Murthy, D. V. 1960. Insects attacking *Striga*. Nature, 187:959

Nag Rag, T. R. 1966. Fungi occurring on witchweeds in India. Commw. Inst. Biol. Control. Technical communication, 7, 75-80.

Nikiema, S. 1992. Conditions agro-écologiques d'infestation du sorgho par *Striga hermonthica* (Del.) Benth. en zone nord-soudanienne du Burkina Faso: Cas de Linonghin. Mémoire de Diplôme d'études Approfondies (D.E.A.) en Sciences biologiques appliquées. Laboratoire de botanique et de biologie végétale, Faculté des Sciences et techniques, Université de Ouagadougou, 68 p.

Okonkwo, S. N. C. 1966. Studies on *Striga senegalensis.* In vitro culture of seedlings. Effect of various sugars and glutamine. Am. J. Bot. 53: 687-693.

Ouedraogo, O. 1995. Contribution à l'étude de quelques Phanerogames parasites des cultures au Burkina Faso: Incidence, biologie et méthode de lutte. Thèse de Doctorat. Université Pierre et Marie Curie, Paris, France, 95pp.

Parker, C. and Riches, C.R. 1993. Parasitic weeds of the world: Biology and Control. CAB Int. Castlefield Press, Kettering, Northants, UK.

Parkinson, V.O. 1989. A survey of infestation of crops by *Striga* spp. in Benin, Nigeria and Togo. Proc. Nova Scotian Inst. Sci., 39: 1-9

Pieterse, A.H., Verkleij, J. A. C., Hollander, D. N.G., Odiambo, G. D., and J. K. Ransom 1996. Germination and viability of *Striga hermonthica* seeds in Western Kenya in the course of the long rainy season. In Advances in Parasitic Plant Research. 6th Int. Par. Weed Symp. Cordoba, Spain. pp 457-464. Monero, M.T. *et al.* Eds.

Pronier I. and Letierce K. 1995. Etude de la biologie d'un insecte, *Smicronyx* (Coléoptère, Curculionidés) susceptible d'être utilisé dans la lutte biologique en région tropicale africaine / Etude des perturbations provoquées par la présence de larves de *Smicronyx* (Curculionides) sur la capsule de *Striga* (Scrophulariacées). Relations avec les travaux effectués dans le cadre d'une lutte biologique. Mémoire de Maîtrise. Université Picardie Jules Verne, Amiens. 99 p.

Sankaran,T. and Rao, V. P. 1966. Insects attacking witchweed (*Striga*) in India. Tech Bull. Commw. Inst. Biol. Control 7:

63-73.

Salako, E. A. 1984. Observations on the effect of *Alectra vogelii* infestation on the yield of groundnut. Trop. Pest Man. 30: 209-211.

Sallé G. and Raynal-Roques A. 1989. Le *Striga*. La Recherche. 206: 44-52

Sauerborn, J. 1991. The economic importance of the phytoparasites *Orobanche* and *Striga*. In: Proc. V Int. Symp. par. weeds, CYMMT, Nairobi, Kenya. J. K. Ransom *et al.* Eds. pp 137-143

Sauerborn, J. 1991. The economic importance of the phytoparasites *Orobanche* and *Striga*. In: Proc. V Int. Symp. par. weeds, (J. K. Ransom, L. J. Musselman, A. D. Worksham and C. Parker, Eds.) pp 137-143 CYMMT, Nairobi, Kenya.

Sauerborn, J., Abbasher, A. A. and J. Kroschel 1994. Biological control of Parasitic weeds by phytopathogenic fungi. In biology and management of orobanche. Pieterse A.H. *et al.* (Eds). Proc. 3rd Int. Workshop on Orobanche and related *Striga* research. Amsterdam, the Netherlands, 545-549.

Siegfried, K. D. 1994. Socio-economic constraints to the adoption of weed control techniques: the case of *Striga* control in the West African Semi-Arid Tropics. Int. J. Pest Man. 40: 153-158.

Singh, B. B. and A.M. Emechebe 1991. Breeding for resistance to *Striga* and *Alectra* in cowpea. Proc. 5th int. Symp. Par. Weeds, Nairobi, Kenya; Ransom *et al.*(eds) pp 303-305.

Smith, M.C., Holt J., and M. Webb 1993. Population model of the Parasitic weed *Striga hermonthica* (Scrophulariaceae) to investigate the potential of *Smicronyx umbrinus* (Coleoptera: Curculionidae) for biological control in Mali. Crop Protection, 12: 470-476.

Smith, M. C. and M. Webb 1996. Estimation of the seed bank of *Striga spp.* (Scrophulariaceae) in Malian fields and the implications for a model of biocontrol of *Striga hermonthica*.

Weed Res. 36, 85-92.

Traoré, D. 1995. Bionomics of *Smicronyx guineanus Voss* and *Smicronyx. umbrinus* Hustache (Coleoptera: Curculionidae), Potential biocontrol agents of *Striga hermonthica* (Del.) Benth. (Scrophulariaceae). Ph. D. Thesis, McGill University of Montreal, 205 p.

Traoré, D., Vincent, C. and R. K. Stewart 1994. Dispersion pattern of adults and vertical distribution of larvae of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera: Curculionidae) on *Striga hermonthica* (Del.) Benth (Scrophulariaceae). Insect Sci. Applic. 15: 479-485.

Traoré, D., Vincent, C., and R. K. Stewart 1996a. Association and Synchrony of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera: Curculionidae) and the parasitic weed *Striga hermonthica* (Del.) Benth (Scrophulariaceae). Biol. Control, 7: 307-315.

Traoré, D., Vincent, C., and R. K. Stewart 1996b. Effects of precipitation on emergence of *Smicronyx guineanus* Voss and *Smicronyx umbrinus* Hustache (Coleoptera, Curculionidae) adults, and soil vertical distribution of pupae. Int. J. of Pest Man. 42: 9-12.

Vallance, K.H. 1950. Studies on the germination of of the seeds of *Striga hermonthica*. The influence of moisture treatment, stimulant dilution, and after ripening on germination. Ann. Bot., 14, 347-363.

Williams, C. N. and Caswell, G. H. 1959. An insect attacking *Striga*. Nature, 184: 1668.

Wilson Jones, K. 1955. Further experiments on witchweed control.II. The existence of physiological strain of *S. Hermonthica*. Empire J. Exp. Agric. 23:206.

Zummo, N. 1977. Diseases of giant witchweed, *Striga hermonthica* in West Africa. Plant Disease Reporter, 61:428-430.