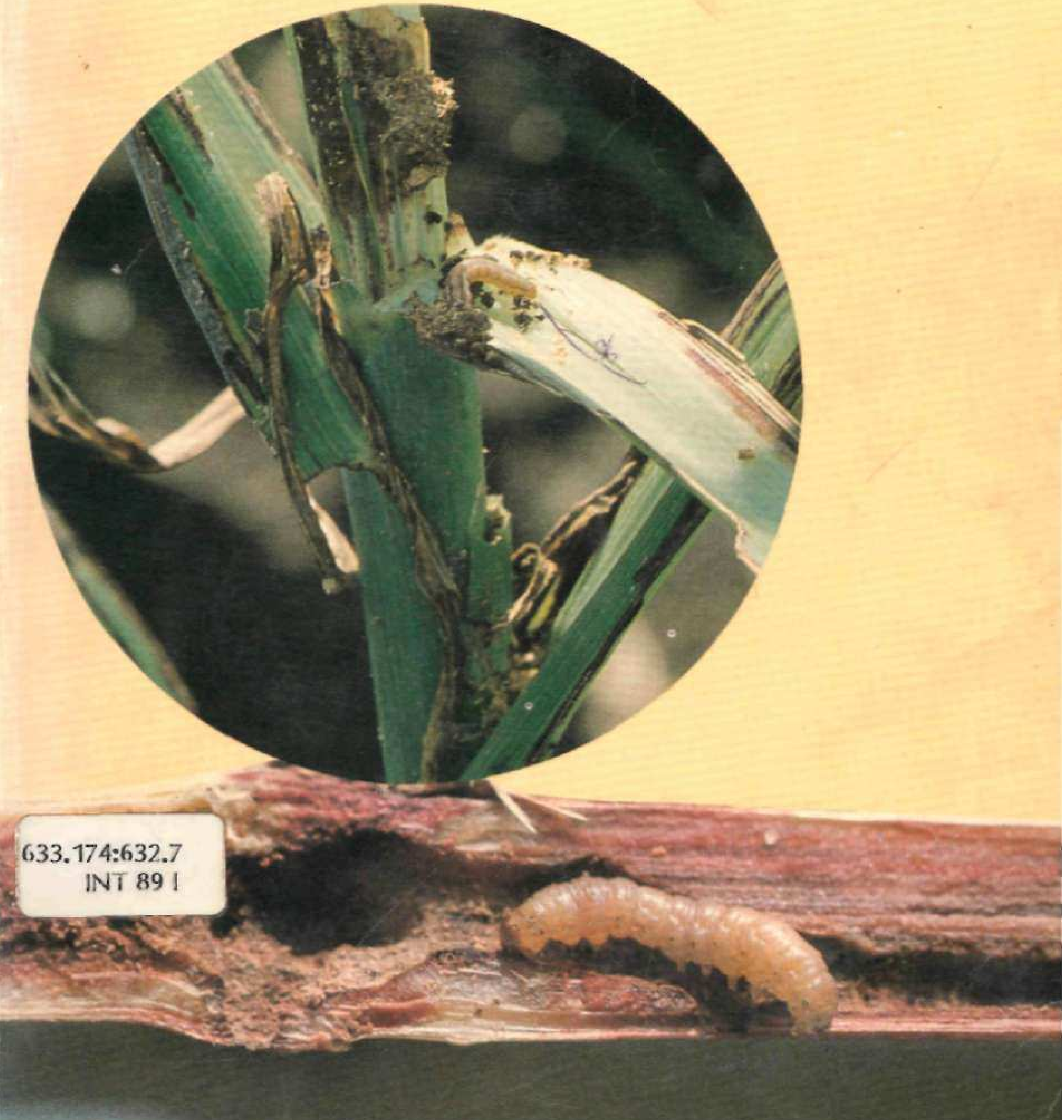
International Workshop on Sorghum Stem Borers



Cover: Stem borer larval *(Chilo partellus)* damage on sorghum plant (above), and stem tunneling (below).

International Workshop on Sorghum Stem Borers

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ICRISAT Center, India

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Welcome Address

L.D. Swindale[1]

Good morning, ladies and gentlemen. It is my pleasure to welcome you to this International Workshop on Sorghum Stem Borers. Some of you have been here before and have spent various lengths of time with us. It is my pleasure to welcome old colleagues and to those of you for whom this is a first visit to ICRISAT, I extend a special welcome. I hope that you will take this opportunity to learn about ICRISAT and what we do here, besides sorghum and stem borer research. I am pleased to note that you will have a half day field trip to see ICRISAT field work and I hope that you will take the opportunity to see what else is going on here at ICRISAT Center.

It has been raining a lot for the last few days, the climate is rather nice and cool, but the rains have come very late this year and generous at somewhat the wrong time. During the main rainy season we had very little rain and crops have suffered badly. Crops that are in the field, particularly those that are mature, show evidence of grain weathering and mold. This applies to some of the crops that have been left to stand beyond the normal harvesting date for you people to see. I hope you will keep this in mind as you tour the fields, that these crops have been left standing to accomodate your visit and do not represent ICRISAT's normal crop management practices.

Sorghum is a very important crop in the diets of millions of people, particularly in Asia and Africa where over 90% of the sorghum produced is used for human food. But it is also important in other parts of the world, particularly in the Americas. Sorghum is one of ICRISAT's five mandate crops, the others being pearl millet, pigeonpea, chickpea, and groundnuts. We have a geographic mandate area, the semi-arid tropics, hence the name ICRISAT, the International Crops Research Institute for the Semi-Arid Tropics. As you know, the crops I have mentioned, particularly sorghum, pearl millet, pigeonpea, and groundnuts are crops of the semi-arid tropical regions, so to that extent our crops mandate and our geographic mandate converge very well.

Research on sorghum started in 1972 with the establishment of ICRISAT Center, and sorghum insect pest research at ICRISAT Center was initiated two years later in 1974. We concentrate on four major groups of insects: shoot fly, midge, stem borers, and head bugs.

Because this workshop is dealing particularly with stem borers, let me say a few words about this group of insects. Here in India, at ICRISAT Center, we concentrate on the spotted stem borer *Chilo partellus.* In eastern and southern Africa, research also concentrates on this stem borer. In West Africa, the maize stalk borer, *BusseoJa fusca,* is of primary concern.

The severity of stem borer damage can result in severe loss of crop stand when seedlings are attacked, or in the case of later infestations, stem tunneling, which weakens the stem and results in stem breakage and unfilled grains. Losses caused by stem borers have been reported to be between 5-15% in West Africa, and 18-27% in East Africa. In India, reported losses range as high as 55-83% on certain susceptible hybrids and varieties, although I am sure that this is not a normal occurrence. If we did nothing to minimize these losses, with all the other insect pests and various biotic and abiotic yield reducers, it would be very difficult for farmers to grow good crops, particularly for small farmers of the semi-arid tropics, which constitute our main target group.

It is extremely important that our research, and I would suggest, your research, be aimed at increasing the output of this important grain. Increasing yield per unit of cost is the most important way in which we can help the poor people of the SAT and of the world, the people

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who depend upon this type of commodity for their livelihood. By reducing the impact of yield reducers we are doing just that.

It is true we can control these pests with insecticides. But chemical control of stem borers is not practical in subsistence agriculture or with this low cost crop in general. Adjustment and initiation of other practices appears to hold more promise. Cultural practices, manipulation of planting dates, crop rotations, and intercropping can all help to avoid pest damage. So will the use of parasites and predators, although these have not proved particularly successful in stem borer control. That is why at ICRISAT, we emphasize host-plant resistance (HPR), hoping to put as much technology into the seed and then transfer that seed to small farmers in the most efficaceous way. HPR is economic, efficient and a long-term approach to be used, either alone or in combination with other methods in an integrated pest management system.

From the initial identification of the major borer species of importance in sorghum in the 1970s, we have moved closer towards providing the component parts for the management of this pest. These are:

- Our field research on resistance to stem borers is conducted in India at Hisar under natural infestation and at ICRISAT Center under artificial infestation.
- Resistance screening techniques have been standardized and are also being used at various other locations.
- We have so far screened 18 600 entries in the germplasm collection and have identified 70 resistant sources, some of which are being used in our breeding program.
- Ovipositional nonpreference and antibiosis are the major mechanisms of resistance to *Chilo,* and we have identified various sorghum genotypes with different resistance factors.
- We have a new and modern insect-rearing laboratory at ICRISAT Center which has greatly facilitated the screening and selection processes of large quantities of germplasm and breeding materials, as well as allowing us to conduct specific studies on insect-pest/ host-plant interactions.
- Emphasis has also shifted to our African programs. ICRISAT entomologists are now based in Zimbabwe and Niger where the focus is also on borers. We expect to have an entomologist based in Kano, Nigeria, in early 1988 and another one probably supplied by IRAT in Bamako, Mali as well.

Dr de Wet and his colleagues will tell you what strategies are used in our breeding program for stem borer resistance. Obtaining high levels of resistance to stem borer is difficult. Entomologists are able to produce levels of artificial infestation in the field that virtually no cultivar of sorghum is able to stand up to. Yet, even under very high levels of infestation, we can find entries that sustain less than 25% seedling damage in the form of deadhearts. Now I wonder if you need to do more than that. During the course of this meeting I would like you to consider whether we really need to try to get resistance higher than 25% deadheart. If we can have that level of tolerance under high levels of infestation then perhaps we have accomplished what we really need to accomplish in host-plant resistance.

I would like to acknowledge the presence of representatives from various organizations with whom we collaborate in stem borer research, including the Overseas Development Natural Resources Institute (ODNRI), the International Centre of Insect Physiology and Ecology (ICIPE), the All India Coordinated Sorghum Improvement Programme (AICSIP), and Haryana Agricultural University (HAU). I am also pleased to note the presence of delegates from the United States Department of Agriculture (USDA), the Institut de recherches agronomiques tropicales et des cultures vivrieres (IRAT), the Commonwealth Agricultural Bureau International (CABI); and National Programs from several African countries, India, and Central America.

You have set aside half a day to review not only your recommendations and discussions but your programs of work. I am really keen that you should give us the benefit of your advice and counsel on ICRISAT's sorghum stem borer research and what you think it should be. At present we are in a very active planning stage preparing for a new five-year program of work. This is a very good time for you to give us your advice on what we should do for you. We see our efforts as part of a dynamic overall system, where changes of condition and changes in research emphasis are essential to keep us vital. With that, I wish you all a successful workshop.

Before I pass on to the next speaker, I wish to pay homage to adynamic statesman. President Kountche of Niger was a foremost and most concerned citizen of his country who put the well-being of the Sahelian farmers and increased agricultural production as the priority of his priorities. Under his leadership, ICRISAT received full support and encouragement for our activities at the Sahelian Center. I remember during my visit with him in August 1985, he emphasized that we should increase not only cereal production in Niger but more importantly, maximize productivity.

I ask you all to stand up and join me in one minute of silence.

Introduction

J.M.J. de Wet[1]

Welcome to the Cereals Program, and particularly the entomology research unit which has organized this workshop. I hope your stay at ICR1SAT will be pleasant and productive, and that you will find the time to visit with scientists of other research units, not only in cereals, but also the Legumes and Resource Management Programs. The Cereals Program has research projects in breeding, pathology, entomology, physiology, and microbiology. Research is strategic and applied in nature, and designed to produce a useful end-product that may be a screening technique, new breeding line, or some basic information required to improve efficiency of our crop improvement programs at ICRISAT Center, Africa, Central America, Mexico, and Caribbean.

During the last fifteen years the Entomology Unit has been successful in developing reliable screening techniques for resistance to the important insect pests of sorghum and pearl millet. This allowed breeders to identify genotypes of these cereals with various degrees of resistance or at least tolerance to sorghum midge, shoot fly, and stem borer. Indeed, a sorghum cultivar resistant to midge, and bred by ICRISAT was released for cultivation in India.

Breeding for resistance to shoot fly and stem borer are receiving special attention at ICRISAT Center at this time. Introducing traits that confer resistance to these pests into elite breeding lines, however, has proved to be difficult. This is not surprising. Resistance seems to be conditioned by several genes that may be distributed across the chromosome complement of sorghum.

This workshop was organized by the Entomology Unit to review the research endeavors in the Cereals Program on stem borer, and to advise on future research directions. In particular, the program would like answers to two basic questions. One is whether stem borer on sorghum is of sufficient economic importance in Africa and Asia to justify further research on control methods. Assuming that the answer is yes, the second question is whether breeding for resistance, chemical control, biological control, agronomic practices, or a combination of these deserves further research. Should the choice include breeding, the program would like to have your opinion on the chances of successfully converting an elite breeding line with fair tolerance to stem borer to a cultivar with true resistance to this insect. The question is, whether such a complex genetic resistance system can be introduced into a highly productive cultivar without upsetting its balanced genetic system.

The Cereals Program is looking forward to your recommendations. I can assure you that they will be considered carefully in planning future research on stem borer control. The Cereals Program has manpower and other resources to solve the stem borer problem if it is solvable. We only wish to be sure that we do not invest resources on a research problem that does not warrant high priority, or in research that has a high probability of failure. I wish you success in your discussions during the next several days.

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Purpose and Objectives

K. F. Nwanze[1]

Ladies and gentlemen, let me add my bit of welcome to you all to this workshop. The International Workshop on Sorghum Stem Borers is a follow-up to the International Sorghum Entomology Workshop held in July 1984 at Texas A & M University, College Station, Texas, USA. Some of you were present at that workshop which set the stage for subsequent ones on insect pests of sorghum. Thus, I hope the present workshop is, in a way the first in a series of workshops that will deal with specific groups of insect pests of sorghum.

Why a workshop on sorghum stem borers? Let me answer this question with others. Why is *Bueseola fusca* devastating in one year and not in others? Why is *Chilo partellus* a severe pest in East Africa and not in West Africa? Why are *Chilo partellus* populations very high in Hisar and very low in Patancheru? Why are natural enemies of stem borers not efficient in controlling stem borers? What are the actual losses caused by stem borers in farmers' fields? If stem borer damage results in yield losses, what is the economic threshold level? Why is stem tunneling not often correlated with yield? What yield factors are more important in stem borer resistance: dead hearts? Stem tunneling? Peduncle damage? Head chaffiness? Do we need higher levels of stem borer resistance, that is, less than 20% deadhearts? To what extent is current research on sorghum stem borer control of relevance to the farmers of the semi-arid tropics (SAT)? What are farmers' perceptions of losses due to stem borer damage? The list of questions continues ad infinitum.

We probably have the answers to some of these questions but I doubt if anyone present here knows all the answers to them. Thus, to bring together entomologists and breeders from across continents, to draw on the advances that have been made on other cereal crops (maize and rice), and to compare notes from other regions, constitutes an attempt at answering the many questions that still remain unanswered.

At ICRISAT we recognize host-plant resistance as a major component in pest management strategies. We also emphasize the need to understand particular pest situations and the biology of the pests, not as an end in itself but as it relates to the crop in particular agroecosystems. We have organized the sessions in such a way that due attention is given to all these aspects. But more importantly, we have provided ample time for discussion after each session, as well as time slots for group discussions and a plenary session, where I hope we will work in concert to identify areas of collaboration, prioritize research objectives, and provide insights into how we can properly manage sorghum stem borers in the SAT. All this is being optimistic, but looking at the caliber of scientists gathered here today, I am confident that we will come away from this workshop satisfied with the efforts that each of us has contributed in making it a success.

Thank you.

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Recent Advances in Sorghum and Pearl Millet Stem Borer Research

K.M. Harris[1]

Abstract

Information on sorghum and pearl millet stem borer research published since 1980 is reviewed, and important advances in knowledge of the biology, ecology, and control of the main pest species of Chilo, Coniesta, Diatraea, Sesamia, Busseola *and some other relevant genera of Lepidoptera are summarized. Progress in the assessment of crop losses, the production of resistant varieties, implementation of biological control, and the development of other nonchemical methods of pest management are assessed and requirements for further research and development are identified.*

Résumé

Progrès récents dans la recherche sur les foreurs des tiges du sorgho et du mil : *L'auteur présente une synthèse de la documentation éditée depuis 1980 sur la recherche concernant les foreurs des tiges du sorgho et du mil en faisant état de progrès importants dans les domaines de la biologie, de l'écologie et de la lutte contre les principales espèces nuisibles des genres* Chilo, Coniesta, Diatraea, Sesamia, Busseola *ainsi que d'autres genres de lépidoptères ravageurs. Les acquis dans les domaines de l'estimation des pertes, de la création de variétés résistantes, de l'application de la lutte biologique et de la mise au point de méthodes autres que celles de la lutte chimique, sont étudiés. Les thèmes de recherche et de développement à élaborer dans l'avenir sont proposés.*

Introduction

Research on the lepidopterous stem borer pests of sorghum was reviewed on a world basis at the International Sorghum Entomology Workshop at Texas A & M University in July 1984 (ICR1SAT 1985) and relevant papers presented at that meeting are referred to later in this review. At the conclusion of the Workshop, general recommendations for future work on sorghum entomology were made and are paraphrased below.

Surveys

- Conduct surveys regularly in major sorghum growing areas to assess pest situations; and
- monitor the possible development of biotypes.

Crop Loss Assessment

- Improve yield loss assessment methods;
- obtain quantitative data on yield losses attributable to pests; and
- develop methods to establish economic injury levels for important pests.

Plant Breeding

- Intensify collection and exchange of insect-resistant germplasm;
- extend screening programs;

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- study insect/ host relationships and insect behavior in greater detail to improve control strategies;
- identify and study resistance mechanisms;
- study the inheritance of resistance; and
- intensify plant breeding for insect-resistant/ stable-yielding varieties and hybrids.

Cultural Control

- Study traditional control practices; and
- emphasize the importance of crop duration, planting dates, crop hygiene, and other agronomic practices in reducing pest incidence.

Biological Control

- Identify natural enemy complexes of sorghum insect pests and determine their efficiency;
- study factors influencing the biology, ecology, and behavior of key natural enemies in cropping systems;
- develop simple strategies to favor natural enemies; and
- determine the effectiveness of exotic natural enemies, especially for use against stem borers.

Chemical Control

- Intensify research on the judicious use of insecticides;
- discourage prophylactic use of insecticides; and
- develop recommendations for insecticide use.

Integrated Pest Management (IPM)

- Develop IPM strategies.

It is now appropriate to consider the advances that have been made since that major meeting on sorghum entomology, and to consider the progress that has been made in sorghum stem borer research during the 1980s. In the brief period of three years since the 1984 Workshop, it is unlikely that many major advances will have been made and this review, which is based on literature published between 1980 and 1987, will inevitably fail to include recent, as yet unpublished work. The following summaries of work on the main stem borer species are therefore intended to provide an introduction to the more detailed consideration of current work which will be the main purpose of this Workshop.

Chilo partellus (Swinhoe)

This is the most important lepidopterous stem borer attacking sorghum, maize, and millet in the Indian subcontinent and East Africa. In recent years more research has been done on this pest than on any other species of sorghum stem borer. Most of that research has been based in India, especially at ICRISAT and at Indian Agricultural Research Institutes and Universities, and in Kenya at the International Centre of Insect Physiology and Ecology (ICIPE). particularly at the Mbita Point Field Station. During the period 1980-87 at least 50 research papers relating mainly to this species on sorghum or maize have been published, including contributions to the Proceedings of the International Study Workshop on Crop-Borers and Emerging Strategies for their Control, held at the Mbita Point Field Station, Kenya, 14 18 June 1982 (Insect Science and its Application, Special Issue, vol.4, nos. 1 and 2); the Proceedings of the International Sorghum Entomology Workshop, College Station, Texas, 15-21 July 1984 (ICRISAT 1985) and the Proceedings of the International Study Workshop on Host Plant Resistance and its Significance in Pest Management, held at ICIPE, Nairobi, 10-15 June, 1984 (Insect Science and its Application, Special Issue, vol.6, No.3). Some of the key papers are noted below and fuller bibliographies are available in the Sorghum and Millets Information Centre, Bibliographies and Newsletter, in Sorghum and Millets Abstracts, in the Review of Applied Entomology, Series A (Agricultural), and in CAB International Annotated Bibliographies.

Biology

The biology of *Chilo partellus has* been studied over many years at various locations in India and East Africa, and is well known. In recent years, Neupane et al. (1985) have published the first detailed account of the bionomics of this species in Nepal; Khan (1983) has studied its biology in Pakistan; Verma and Jotwani (1983) compared the biology and behavior of specimens collected from Delhi, Indore, Nagpur, and Hyderabad, India; and Alghali (1985) studied it in Kenya. Length of lifecycle, time of adult emergence, ovipositing potential, location of egg batches on plants, and incidence of larval diapause vary appreciably between localities. These are possible indicators of the existence of biotypes, and seasonal variability within localities, but the factors determining these variations do not seem to have been fully investigated.

Important research on the behavior of first-instar larvae immediately after hatching, has been continued by Chapman et al. (1983) and Bernays et al. (1985) who have studied the survival and dispersal of young larvae and the mechanisms by which newly hatched larvae reach the leaf whorl from oviposition sites near the base of sorghum plants.

Ovipositional preferences of female moths on 70 different varieties and hybrids were studied by Singh and Rana (1984) but the behavior of ovipositing females, which results in different egg counts on preferred and nonpreferred plants, was not recorded.

Ecology

Few recent studies of *C. partellus* can be considered to be essentially ecological and there seems to be a general lack of rigorous studies of the population dynamics of this pest. A short paper (Mahadevan and Chelliah 1985a) reports the use of lighttraps to monitor seasonal abundance in 1981 - 82 at one location in India, and two papers on the influence of weather on the seasonal occurrence of this species have also been published (Mahadevan and Chelliah 1985c, 1986).

Crop Loss Assessments

There is still a notable absence of objective assessments of sorghum yield losses directly attributable to *C. partellus.* In the period under review, Flattery (1982) published the results of field trials over five years on grain sorghum in Botswana. He noted that there was often an increase in yield when *C. partellus* damage resulted in increased tillering and that the inherent tillering ability of one of the cultivars used in the trials (cv 65D) masked any yield reductions that might have resulted from attacks by this pest. Some yield decreases were recorded following high levels of C. *partellus* attack but were not statistically significant. These results were interpreted by the author as supporting the view expressed by Doggett (1970) that sorghum can produce a good crop and feed a large borer population but that compensatory growth following borer damage may be reduced during periods of stress. Alghali (1986) assessed the effects of cultivar, time of attack, and incidence of infestation on two cultivars in experiments at Mbita Point, Kenya. He concluded that the greatest yield reductions (about 20-25% of control yields which resulted when plants were artificially infested with 5-20 first-instar larvae at six weeks after germination) may not necessarily warrant control, except when planting is staggered and the pest population is high. His research also suggested that infestation later than six weeks after germination may not result in significant losses of grain. The general consensus seems to be that appreciable yield loss results mainly from attack within the first two months of growth, especially from deadheart formation, and that extensive stem tunneling during later growth does not significantly depress yield, but further rigorous investigation of crop losses caused by *C. partellus* seems desirable.

Chemical Control

Chemical control of stem borers on sorghum in Africa and Asia has never been either particularly appropriate or feasible. With increasing costs of insecticide applications and increasing concern about environmental pollution, research on chemical control is greatly reduced. Since 1984, only four papers abstracted in the Review of Applied Entomology (Series A) are directly concerned with chemical control of *C. partellus* on sorghum: (1) Khan (1983) reported that carbofuran and disulfoton, applied in the furrow, were more effective than foliar applications of nonsystemic compounds in Pakistan; (2) Sachan and Rathore (1983) reported a 126% yield increase in Uttar Pradesh, India, of sorghum protected by a program of a soil application of 10% phorate granules, followed by six applications of 4% carbaryl granules to the leaf whorls and a spray application of carbaryl at flowering; (3) Kishore (1984) compared the timing and scheduling of 4% endosulfan dust in India; and (4) Natarajan and Chelliah (1986) reported effective control of *C. partellus with* dust formulations of BHC, carbaryl, malathion, endosulfan and phenthoate, also in India. The general conclusion, at least for India, has been succinctly stated by Leuschner et. al. (1985): "Insecticides should be used as a last resort and only where absolutely necessary".

Plant Breeding

Screening for resistance and, to a lesser extent, investigations of the mechanisms of resistance, have been the main recent research activities on *C. partellus.* Leuschner et. al. (1985) reviewed the role of host-plant resistance in pest management in India and concluded that, with a strong breeding effort, present levels of resistance to this and other key pests could be developed to play an important role in the implementation of IPM in sorghum and that low levels of stem borer resistance could be supplemented with cultural and chemical measures. The techniques used to mass rear *C. partellus* on artificial diets, to establish infestations on sorghum plants and to evaluate resistance have been summarized by Taneja and Leuschner (1985). They emphasized that deadheart formation causes maximum grain yield loss and should be given greatest weight in evaluating resistance. They also noted that antibiosis and tolerance are the main resistance mechanisms.

Teetes (1985) assessed the role of insect-resistant sorghums in pest management, and Srivastava(1985) summarized the results of screening programs up to the early 1980s in India and described a breeding scheme to strengthen stem borer resistance in sorghum. Rana et al. (1985) reviewed information on stable resistance sources, resistance mechanisms, and the genetics of resistance. They concluded that antibiotic mechanisms are more important for stem borer resistance than ovipositional nonpreference.

A detailed laboratory study of the influence of varietal resistance on oviposition and larval development by Singh and Rana (1984) showed that antibiosis, measured in 70 sorghum cultivars, was expressed as slower larval development, higher larval mortality and lower pupal weights, and that factors affecting larval development exist independently in leaf and stem tissues. They compared the results of their laboratory experiments with field observations on the same cultivars and showed that larval duration and larval mortality on leaf whorl tissues were negatively and significantly correlated with both the percentage of deadhearts and the number of tunnels per plant and per stalk. Oviposition in cages was positively and significantly correlated with the percentage of deadhearts and the number of cavities per plant and per stalk. These studies emphasize the importance of successful larval establishment in the leaf whorl of young sorghum plants as the main factor determining deadheart formation and consequent grain yield loss.

Biological Control

Gilstrap (1985) predicted excellent prospects for the biocontrol of *C. partellus* and of other stem borers, both by the conservation of endemic natural enemies and by the introduction of exotic agents, but there are few signs of progress being made in this direction on sorghum.

Inayatullah (1983) studied host selection by the braconid parasite *Apanteles flavipes* (Cameron) and reported that it was especially attracted to frass produced by *C. partellus* and other borers feeding on sorghum and maize. Host-plant associations may be of particular importance to parasitic Hymenoptera and Diptera and merit more detailed study.

Chakrovarty et al. (1983) studied the effects of the bacterium *Serratia marcescens* Bizio, applied as an aqueous cell suspension, which prevented egg hatch and killed first-instar larvae. This and other pathogens also merit more research.

Cultural Control

Seshu Reddy (1985) reviewed the main cultural practices that are used against sorghum stem borers, including: tillage and mulching; time of planting; spacing; fertilizer and water management; crop sanitation; removal of deadhearts, volunteer plants, and alternative host plants; crop rotation; and intercropping.

Intercropping has received most recent attention from research workers. Mahadevan and Chelliah (1985b), studied the effects of intercropping sorghum with various leguminous crops to control *C. partellus* and reported that intercropping with cowpea or lablab reduced stem borer infestation and increased grain and straw yields. Omolo and Seshu Reddy (1985) reported the results of intercropping experiments in Kenya which indicated that sorghum-cowpea intercropping reduced the incidence of *C. partellus* and other borers. More research is needed but much information is already available and could be used by extension workers to advise farmers and to develop IPM programs.

Coniesta ignefusalis (Hampson)

This pyralid species is closely related to *C. partellus* and occupies a similar niche in West Africa. It is mainly a pest of pearl millet but also attacks sorghum in the drier areas of the Sahel. Nwanze (1985) commented on *C. ignefusalis'm* the context of pest management in pearl millet in the Sahel but relatively little research has been done on it. Some progress has been made with biological and other studies during the United States Agency for International Development (USAID)/Food and Agriculture Organization of the United Nations (FAO)/ Comite permanent interetats de lutte contre la secheresse dans le Sahel (CILSS)/IPM Project.

Diatraea saccharalis (Fabricius)

This species also belongs to the family Pyralidae and is therefore relatively closely related to *Chilo* and *Coniesta.* It occurs in tropical and subtropical areas of the USA, the Caribbean, Central and South America and mainly attacks sugarcane, maize, and sorghum. Information on its biology and ecology is reviewed in Harris (1989). It is therefore the Western hemisphere equivalent of *C. partellusand C. ignefusalis* with biological similarities which indicate that research on all three species may be interrelated, especially in the contexts of biological control and in selecting for resistance. Mihm(1985) reported methods of artificial infestation and the evaluation of resistance in sorghum against this species and Guiragossian and Mihm (1985) reviewed progress made in screening 200 sorghum lines during a Centro Internacional de Mejoramiento de maiz y Trigo (CIMMYT)/ICRISAT cooperative program in Mexico. Some results of screening in Brazil have also been reported (Boica et al. 1983; Boica and Lara 1983, and Lara and Perussi 1984). Tolerance is the main type of resistance detected in these studies with low levels of antibiosis and of ovipositional nonpreference.

van Leerdam et al. (1985) studied the host-finding behavior of the braconid parasite, *Apanteles flavipes* (Cameron) and found that a water soluble substance present in fresh *D. saccharalis* frass was attractive to female parasites searching for hosts. These observations parallel those made on the same parasite on *C. partellus* in Pakistan (Inayatullah 1983).

Busseola fusca (Fuller)

This is the most important noctuid stem borer attacking sorghum in Africa south of the Sahara and it has probably been associated with cultivated sorghum since the earliest origin of the crop in Africa. Although it is a widespread and important pest, little detailed research has been done on this species in recent years. Adesiyun (1983) studied the effects of intercropping sorghum, maize, and millet in Nigeria and concluded that the almost total inability of *B. fusca* females to oviposit effectively on millet resulted in reduced infestations of sorghum when intercropped with millet, which is a common practice in the drier areas of West Africa. Gebrekidan (1985) recorded that nearly 6000 indigenous Ethiopian sorghums were evaluated in a natural 'hot spot' infestation of *B. fusca* but less than 1 % showed tolerance.

Most recently, van Rensberg et al. (1987) have published a detailed account of the ecology of *B. fusca* on maize in South Africa. The results of this work are partly relevant to research on sorghum and are referred to in a later paper presented at this Workshop (Harris 1989).

Sesamia cretica Lederer

Temarak et al. (1984) have studied the interaction of the braconid parasite, *Bracon brevicornis* Wesmael and its hyperparasite, *Pediobius bruchida* (Rondani) with overwintering populations of *S. cretica* in stacked sorghum stems in Egypt. Larval mortality rates of 14-68% were recorded, with parasitism accounting for 5-28%. By the end of the winter hyperparasitism by *Pediobius* had risen to 100%. The only other recently published work on this species seems to be that by Ba Angood and Hubaishan (1983) reporting the screening of several introduced high-yielding sorghum varieties in the Yemen Democratic Republic. The introduced Dwarf White Milo was very susceptible; the lower-yielding local variety Baini was less susceptible; and the optimum sowing dates for most varieties tested were 26 August and 16 September.

Other *Sesamia* Species

Although other species of *Sesamia* have been recorded as stem borers of sorghum (Harris 1985; Seshu Reddy 1985) little research is being done on them, indicating that they are generally considered of less importance than the main stem borer species dealt with above.

Eldana saccharins Walker

In the past this has been considered a relatively unimportant pest in Africa, except on sugarcane. But Seshu Reddy (1985) noted that it has recently increased in importance on sugarcane, maize, and sorghum in several areas of Africa south of the Sahara, and it is the most important stem borer of sorghum in Burundi. Sampson and Kumar (1985) published an account of its biology and ecology on sugarcane in Ghana and Atkinson (1980) published a detailed account of its biology, distribution, and host plants in South Africa.

Conclusions

During the 1980s, progress has been made towards mainly empirical solutions of stem borer problems by selecting for host-plant resistance and incorporating resistance into higher-yielding varieties. Screening techniques, especially for *Chilo partellus* and *Diatraea saccharalis,* are well established and could easily be adapted for other species.

The mechanisms of resistance have not been fully researched, although some progress has been made in studying the critical phase of establishment of first-instar larvae of *C. partellus* on young sorghum plants. Other interactions between pest species and their host plants, both in the adult and larval stages, merit further research which could provide the basis for a better understanding of resistance. If resources were adequate, which they are not at present in either Asia or Africa, studies of borer species on their original grass hosts might also provide the basis for further advances in plant breeding.

Some work on chemical control continues and may be of use in some special circumstances but seems unlikely to provide feasible long-term solutions.

Cultural methods of limiting borer damage are available but are seldom used effectively in areas where farming communities lack the support of adequate advisory services.

Biological control, which offers some possibilities of effective long-term control, will require substantial research and implementation inputs if it is to be successful. Ingram (1983) reviewed the position and suggested further work.

Campion and Nesbitt (1983) have reviewed the use of pheromones for stem borer control and concluded that the main potential for control by mating disruption would be on rice, maize, and sugarcane grown as plantation crops.

Finally, we do now have a better understanding of the effects of stem borers on sorghum grain yields but truly objective assessments of crop losses are still relatively rare and, in their absence, there may still be cases where subjective assessments overestimate pest status, especially during the later stages of crop development.

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Regional Reports

Sorghum Stem Borers in India and Southeast Asia

R.D. Chundurwar[1]

Abstract

Information on the distribution, bioecology, and host plants of sorghum stem borers is reviewed. The sorghum stem borer species recorded in India and Southeast Asia, their avoidable losses, and control tactics are discussed, together with their natural enemies including pathogens. Their potential for use in the control of stem borers is discussed.

Résumé

Les foreurs des tiges du sorgho en Inde et en Asie du Sud-Est : Des données sur la distribution, la biologie et les plantes hôtes des foreurs des tiges du sorgho sont récapitulées. Les espèces signalées en Inde et en Asie du Sud-Est sont décrites ainsi que les pertes évitables et les stratégies de lutte y compris l'utilisation d'ennemis naturels, dont des agents pathogènes. Leur potentiel dans la lutte contre les foreurs est examiné.

Introduction

Of the 19.22 million ha of sorghum grown throughout Asia, India accounts for 15.30 million ha with a total production of 10.30 million tonnes (FAO 1985). At the beginning of the century, Indian sorghum yields averaged 498 kg ha^{-1}. Production averages increased to 673 kg ha^{-1} by 1985 mainly due to the introduction of hybrids and improved varieties in various states.

Sorghum is an important grain and fodder crop of India. Approximately 90% of the country's sorghum is grown in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Tamil Nadu. Sorghum grain is primarily used as human food in rural areas, while stems and leaves provide fodder for cattle.

In Southeast Asia, sorghum is grown in Bangladesh, Burma, Indonesia, Sri Lanka, Taiwan, Thailand, and the Philippines. In Bangladesh, sorghum is cultivated as a relay, mixed, or border crop, and rarely grown as a monocrop. Sorghum is rapidly gaining popularity in the Philippines as an economical feed supplement for poultry and cattle. In the central part of Thailand, sorghum is grown on marginal areas, or planted as a second crop after maize for export to Japan, Saudi Arabia, and South Korea. Very little sorghum is grown in Indonesia or any of the other Southeast Asian countries and very little sorghum research has been done in those countries (Meksongsee and Chawanapong 1985).

Important stem borers in different sorghum growing regions in India have been reviewed (Seshu Reddyand Davies 1978,Gahukarand Jotwani 1980, Srivastava 1985, and Sharma 1985). A review of world literature on lepidopterous stem borer listed 46 species of borers on different crops (Jepson 1954). Other valuable research on these borers include the area of systematics (Kapur 1950, 1967, Tarns and Bowden 1953, and Bleszynski and Collins 1962), and biology, injury, and control tactics (Ingram 1958, Nye 1960, Harris 1962, 1985, Young 1970, and Young and Teetes 1977).

The major stem borer species associated with sorghum in India and Southeast Asia have been compiled (Table 1) from CAB Annoted Bibiliographies, E-105 issued by Commonwealth Institute of Entomology (1973-83). The following documents

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various stem borer complexes found throughout India and Southeast Asia, with attention to species distribution, occurrence, host plants, damage and extent of crop losses, control tactics, and natural enemies.

Damage and Extent of Losses

In India, incidence of stemborers ranges from 10-75% with severe infestations that can necessitate resowing of the crop (Rahman 1944, Trehan and Butani

Table 1. Sorghum stem borers, their distribution and hosts in India and Southeast Asia[1].

Stem borer	Distribution	Host plants
A. Pyralidae		
Chilo partellus (Swinhoe)	Andhra Pradesh, Assam, Bihar, Delhi, Gujarat, Himachal Pradesh, Karnataka, Maharashtra, Orissa, Punjab, Rajasthan, and West Bengal States of India; Indonesia, Srilanka, and Thailand. (CIE Map, 184)	Sorghum, maize, millet. rice, sugarcane, bajra sudan grass, ragi, Johnson grass. Job's tear, and Kawdia
Chilo infuscatellus (Snellen)	Andhra Pradesh, Assam (Shillong) Bengal, Bihar, Coimbatore, Delhi, Gujarat, Kerala, Madhya Pradesh, Maharashtra, Mysore, Orissa, Rajasthan, Tripura, and Uttar Pradesh States of India. Indonesia (Java), Korea, the Philippines, Taiwan, Thailand, and (South) Vietnam. (CIE Map 301)	Sugarcane, millet, sorghum, and rice
Chilo auricilius (Dudgeon)	Andhra Pradesh, Assam, Bihar, Darjeeling, Delhi, Gujarat, Himachal Pradesh, Madhya Pradesh, Maharashtra, Mysore, Orissa, Punjab, Rajasthan, and Tamil Nadu States of India. Malaysia, the Philippines, Taiwan, Thailand, and Vietnam. (CIE Map 300)	Sugarcane, rice. and sorghum
Chilo sacchariphagus (Bojer) (= *Proceras venosatus* Walker)	Indonesia, Malaysia, and People's Republic of China (CIE map 177)	Sorghum and sugarcane
Maliarpha sopartella Rogonot	India (Ludhiana)	Rice and sorghum
Ostrinia furnacalis Guenee	Assam, Bihar, Manipur, Mysore, Punjab, and West Bengal States of India. Indonesia, Korea, Malaysia, Srilanka, Taiwan, Thailand, and Vietnam. (CIE map 294)	Maize, millet, and many grasses
B. Noctuidae		
Sesamia inferens (Walker)	Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Mysore, Orissa, Punjab, Uttar Pradesh, and West Bengal States of India. Indonesia, Japan, Korea, the Philippines, Srilanka, Taiwan, and Thailand. (CIE map 237)	Sorghum, maize, millet, sugarcane, and grasses

1. Source: Commonwealth Institute of Entomology (CIE), Distribution Maps of Pests, 56, Queen's Gate, London, England.

1949, and Pradhan and Prasad 1955). Overall losses due to stem borers may average 5-10% in different regions in India for early-sown sorghum. Avoidable losses with the CSH 1 hybrid and the variety Swarna have been estimated to be 55-83% (Jotwani et al. 1971, and Jotwani and Young 1972).

Stem borer severity on sorghum has ranged from 54-100% in different years over the last decade. Damage of 60-70% has been reported in Rajasthan, for both the CSH I hybrid and local varieties. It ranged from 80-100% in Coimbatore, Dewas, Indore, Mansoor, Nagpur, Ratlam, Sehore, and Udaipur districts. Besides these cases, peduncle damage has been reported from Madhya Pradesh on CSH 5, and severe infestations were reported on late sown sorghum in Karnataka and early sown sorghum in Gujarat (AICSIP 1975-87).

Trials conducted at Hisar on plots under intensive protection compared with nonprotected plots, have shown high yields in protected plots and very low yields in nonprotected plots. Infestation ranged from 50-100% under field conditions (Taneja et al. 1987).

Major Stem Borer Species

Chilo partellus (Swinhoe)

The species *C. partellus,* known as the spotted stem borer, is distributed in Bangladesh, India, Indonesia, Sri Lanka, and the Philippines. It is a major pest of sorghum, maize, and sugarcane. *C. partellus* has been recorded on other host plants, including Sudan grass *(Sorghum vulgare),* Nachini *(Eleusinae coracaua),* Baru Johnson grass *(Sorghum halepense).* Jobs tears *(Coix Lachryma* Jobi L), and Burger *(Polytoca harbata)* (Trehan and Butani 1949). The borer is found throughout the Indian subcontinent and is a more serious pest in northern and central regions.

Population dynamics and seasonal abundance studies at Coimbatore have revealed that adult activity is higher in January than in other months, with highest damage on the crop sown during March and lowest on the crop sown in June or October (Mahadevan and Chelliah 1986). In Maharashtra, the number of larvae were found to be higher in winter sorghum than in rainy season sorghum. But the average number of pupae, percentage of stem tunneling, and percentage of internodes attacked, were highest in rainy season sorghum.

Many scientists reported *C. partellus carryover* in stalks and stubble of sorghum (Rahman 1944, Rawat 1967, Singh et al. 1975, Chundurwar 1978, and Taley and Thakre 1980). The metamorphosis of moths from pupae has been reported to occur from the beginning of April to June in northern India (Rahman 1944, Trehan and Butani 1949, Panwar and Sarup 1979, and Singh et al. 1985). In Maharashtra, emergence of adults was observed in June or July, but emergence started at Gwalior at the end of February and continued through the end of April. Environmental conditions, primarily rainfall, determines the time of emergence of adults.

The biology and behavioral response of larvae have been studied in the laboratory. In a comparison of larvae collected from Delhi, Hyderabad, Indore, and Nagpur, the larval population from Delhi laid more eggs and completed life cycles quicker than the others. In addition, 91.8% of larvae from Delhi underwent diapause (Verma and Jotwani 1985).

Chilo infuscatellus Snellen, and *Chilo auricilius* (Dudg)

These two species of pyralids are primarily of economic importance to sugarcane and of minor importance to sorghum. Both have been reported on sorghum in India, Indonesia, the Philippines, Taiwan, and Thailand'. *C. infuscatellus* has been collected in Madhya Pradesh, in central India, on maize and sorghum hybrids. The biology and nature of damage are similar to *C. partellus.* The borer *C. auricilius* is primarily a pest of rice, commonly known as the gold-fringed rice borer.

Chilo sacchariphagus (Bojer)

This species occurs in China, Indonesia, and Malaysia and is primarily a pest of sugarcane. It is known as the spotted borer. It is an important pest of sorghum in Hopei province of China. The first-instar larva is a leaf-feeder, concentrated in the plant whorl and the second-instar and the older larvae tunnel in the stem. There are two generations per year. Peak oviposition occurs in mid-June for the first generation and in mid-August for the second generation. *C. sacchariphagus* damage in spring sorghum has been reported at 65% and in summer sorghum at 35%. Losses reported from borer damage are 32% for spring sorghum and 8% for summer sorghum.

Maliarpha separatella (Ragonot)

The species, known as the green striped borer, is reported to be a major pest of rice in Africa. The larvae were first observed in Ludhiana, India in the stubble and lower stems of the CSH 1 sorghum hybrid. The biology and behavior of the pest has been reported by Sandhu and Chandra (1975).

The adult moth is stout, measuring about 20-25 mm, with prominent dark red bands on the fore-wings, especially on adult females. Eggs are laid in batches and are yellowish-white and oval. The larvae exhibit sexual dimorphism. The male larvae have five violet-to-reddish stripes while females have faintly defined stripes or none at all. The larval period lasts for 6-9 days in the laboratory. Pupation occurs in stems or stubble and lasts for 14-16 days. An average of one larva per stubble was recorded in the field.

Ostrinia furnacalis (Guenee)

The species is known as the tropical corn borer and is distributed in parts of China, India, Korea, Malaysia, Sri Lanka, Taiwan, Thailand, and Vietnam. This species was first reported in Thailand as *O. salentialis* (Snellen). It is an important pest of maize in Thailand and the Philippines, but infestation on sorghum is rarely observed. Succulent varieties of sorghum have been found susceptible to this species in Thailand.

Sesamia inferens (Walker)

This species occurs in Burma, China, India, Indonesia, Malaysia, Sri Lanka, Taiwan, and the Philippines (Teetes et al. 1983). It is known to be a pest of sugarcane, maize, sorghum, rice, wheat, and finger millet (Jepson 1954). It has been reported attacking sorghum in the Philippines (Young 1970). In Thailand, is a pest of both sugarcane and rice, but it has not been reported on sorghum (Meksongsee and Chawanapong 1985). In India, it is minor rice pest and causes considerable damage to maize (Kapur 1967).

The detailed biology of *S. inferens* has been studied in finger millet by Krishnamurti and Usman (1952). The adult moths are straw colored. Female moth lays creamy white eggs in clusters between the leaf sheath and stem of the plant. Eggs hatch in about 7 days but hatching may be extended in a winter or dry season. On hatching, larvae may penetrate the stem directly and can kill the young plant. The full-grown larva measures 25-30 mm in length and is pale yellow with a pink tinge and a reddish-brown head. Several larvae may be present in one gallery. Pupation takes place inside the tunneled stem. The life cycle from egg to adult is completed in 46 days in summer and 71 days in winter. Four-to-six generations are recorded per year in south India. Symptoms of damage are similar to those caused by *C. partellus.*

Insect Control and Related Research

Chemical Control

In India, considerable work has been done on chemical control of *C. partellus* at the Division of Entomology (IARI, New Delhi), by the All India Coordinated Sorghum Improvement Project (AICSIP), and at various agricultural universities. In early trials, insecticides such as BHC and DDT applied as sprays and dusts, proved effective in controlling stem borers on local sorghums. Later spray formulations of insecticides such as parathion, diazinon, trichlorphos, carbaryl, malathion, and endosulfan have proven effective in reducing the pest (Sukhani 1986). The effectiveness of granular insecticides was tested for carbofuran 3%, chlorfenviphos 2%, and fensulfothion 5%, applied at 8, 10, and 12 kg per ha^{-1} in leaf whorls (Vibhute et al. 1973-74, and Srivastava and Jotwani 1976). Other chemical controls were tested on high-yielding varieties and hybrids of sorghum, such as endosulfan (Kundu and Sharma 1974), phorate and chlorfenviphos, mephosfolan aldicarb, quinalphos, disulfoton, and a mixture of lindane and carbaryl (Venugopal et al. 1977, Srivastava and Jotwani 1979, Jotwani 1979, Kundu and Kishore 1980, and Patel and Jotwani 1982). Results revealed that carbofuran and endosulfan granules were the most effective of the insecticides tested at different locations.

Trials were also conducted at Delhi, Kanpur, Parbhani, and Udaipur, on comparative effectiveness of proved granular and foliar sprays of different insecticides. Tested under the AICSIP program, the granular insecticides proved superior when applied in whorls.

Insecticides such as endosulfan 4%, carbaryl 5%, lindane 0.65%, phenthoate 2%, applied as dusts at reduced dosages of 8-10 kg ha^{-1} in the leaf whorls, proved effective and economical (Sadakathulla 1981, and Jotwani 1982). In China, application of granules containing 0.25% demeton gave 80% control of stripped borer *C. sacchariphagus* (Anonymous 1977). Very little work has been done on chemical control of other species of borers on sorghum.

Biological Control

A number of parasites and predators of stem borer have been recorded by various scientists (Rao 1964, Sharma et al. 1966, and Jotwani, et al. 1978). Recently, a large number of parasitoids have been reported from Dharwad. Considerable information is also available from other parts of the world and reviewed by Van Rensburg and van Hamburg (1975), and Greathead (1971).

In India, attempts were made to control *C. partellus* by releasing strains of egg parasite *Trichogramma exiguum* from Barbados, Colombia, and the Philippines in different ecological areas. The parasite has been established in Delhi and Nagpur areas (Jotwani 1982). Recent releases of egg and larval parasites *Trichogramma chilonis* and *Apanteles flavipes* have been successful, attacking *C. partellus* in sorghum penduncle with up to 65.5% mortality (AICSIP 1986-87).

A vast amount of literature is available on pathogenic microbes, i.e. fungal, bacterial, and viral diseases of stem borers. Ramakrishnan and Kumar (1977) reviewed the work done on pathogenic microbes in India. The fungus *Fusarium aleyrodis* proved effective in controlling the stem borer when sprayed either in spore suspension or crude toxin (Sinha and Prasad 1975). Similarly, the granulosis and nuclear polyhedral virus of different strains were reported on *C. infuscatellus, C. sacchariphagus,* and 5. *inferens* in India (Easwarmoorthy and David 1979, Nayak and Srivastava 1979). Bacterial disease caused by *Serratia marascens* has been recorded from *C. infuscatellus* in sugarcane (Sithanatham 1979). Although useful information is available on parasitoids and insect microbes that attack the stem borer complex, a systematic use of these biotic agents has not been exploited.

Conclusion

From the present level of knowledge on the control of stem borers, it is obvious that the damage caused by this pest could be reduced in India, and in Southeast Asia. Economic threshold levels for different stem borers should be investigated so that appropriate control measures can be recommended at the appropriate time. Critical studies are needed on pest population and their natural enemies (including parasites, predators, and pathogenic microbes), and behavioral response to different species of stem borer.

Information on bioecology, occurrence, and population dynamics of borers is scanty in Southeast Asia and further work is needed in the region. The research on biocontrol aspects in different ecological regions has to be given priority along with other control tactics.

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Stem Borers of Sorghum in West Africa with Emphasis on Nigeria

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Abstract

Lepidopterous stem borers are the main insect pests of sorghum in West Africa. Their relative importance, distribution, bioecology, and the damage they cause are described. The various control strategies that include cultural, genetic, biological, legislative, and chemical methods and the integration of these approaches into a pest management system are discussed.

Recent changes in cropping patterns in the sorghum-growing areas of West Africa may have influenced the incidence levels and damage caused by stem borers. Future research needs are also indicated.

Résumé

Les foreurs des tiges du sorgho en Afrique de l'Ouest : Les lépidoptères foreurs des tiges sont les principaux ravageurs des cultures de sorgho en Afrique de l'Ouest. Leur importance relative, leur distribution, leur bioécologie ainsi que les dégâts provoqués par ces insectes sont présentés. Les différentes techniques de lutte (culturale, génétique, biologique, chimique) y compris l'aspect législatif sont examinés ainsi que l'intégration de ces différentes approches dans un système de lutte amenagée contre ces ravageurs.

Les modifications récentes des systèmes de culture dans les zones de production du sorgho auraient influencé l'incidènce et l'intensité des dégâts provoqués par les foreurs. Les thèmes de recherche à élaborer dans l'avenir sont proposés.

Introduction

Sorghum or Guinea corn, *Sorghum bicolor* (L) Moench, is the most widely cultivated cereal crop and the most important food crop in the savanna areas of West Africa. Its importance can be illustrated with the situation in Nigeria, the major producer, where it accounts for about 50% of the total cereal production and occupies about 46% of the total land area devoted to cereal production (other cereals are rice, maize, millet, and wheat). The area devoted to sorghum is slightly more than 6 million ha and production is estimated to be about 9 million metric tonnes (IAR 1984). These factors indicate that the crop will continue to increase in importance in Nigeria and other countries in the region although similar figures for other West African countries are not readily available.

Species Complex

Insect pests constitute an important factor limiting grain sorghum production in West Africa. The most important field insect pests are shoot flies, stem borers, head bugs, head caterpillars, and grain midges. Of these, the stem borers are the most important and most widespread. Much of the work on the insect pests of sorghum in the region has therefore been *on* stem borers.

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Stem borers reported on sorghum in West Africa include *Busseola fusca* (Fuller), *Sesamia calamistis* Hampson, *Eldana saccharina* Walker, *S. poephaga* Tarns and Bowden, *S. Penniseti* Tarns and Bowden, and *Acigona ignefusalis* Hampson. *A. ignefusalis* is primarily a pest of pearl millet, *Pennisetum americanum(L.)* Leeke, but is a minor pest of sorghum in a sorghum/millet intercrop. Although details vary between countries, *B. fusca* is the most important stem borer since it predominates in the major sorghum-growing areas. Other species can be of primary importance locally. For example, *S. calamistis* predominates and *E. saccharina* is important in the southern Guinea savanna in Nigeria (Abu 1986a, b), while *A. ignefusalis* is more important north of latitude 11° 30'N in Burkina Faso (Nwanze, ICRISAT, personal communication). The relative importance and distribution of stem borers in West Africa is strongly influenced by rainfall patterns.

Control Measures

Cultural Control

The most logical cultural control measure against *B. fusca,* which spends the dry season in diapause, is to reduce the first generation adult population by killing diapausing larvae within the old stalks. This is best done by destroying old stalks by burning or composting before the onset of the rains (Harris 1962). Where the stalks are required for building, fencing, or firewood they should be partially burned; the leaves should be burned a few days after the heads have been removed, while the leaves are dry but the stalks are not (Adesiyun and Ajayi 1980). Heat generated from burning leaves is sufficient to kill the larvae within the stalks. The stalks should be kept in the open rather than in large stacks in the shade of trees where larval survival is much higher. Where the stalks are fed to animals, the residues and all unused stalks should be destroyed before the onset of the rains.

For these cultural control measures to be effective, they must be adopted by all farmers in the target area, otherwise, remaining insect populations will continue to seek available hosts. One way to accomplish this is to enlighten the farmers adequately or, if possible, enforce compliance by legislation.

Sesamia can also be controlled by partial burning. In the southern Guinea savanna, where sorghum ratoons support the carryover of *Sesamia* populations through the dry season (Abu 1986b) it is advisable to plow ratoons into the soil.

For both *B. fusca* and *Sesamia,* early planting has been found to lower stem borer infestation (Abu 1986a). This probably explains why peasant farmers, who normally plant as soon as the rains become established, suffer less stem borer infestation than occurs at experimental stations, where planting is usually delayed.

Another cultural control measure involves intercropping. Peasant farmers in West Africa almost invariably intercrop millet and sorghum. Available information (Adesiyun 1983) indicates that interplanting millet with sorghum in alternate stands within the same row reduces larval infestation of *B. fusca* on sorghum, since the adults do not effectively utilize millet for oviposition.

Resistant Varieties

In West Africa, the use of insecticides is largely beyond the means of the small farmer, and recommended chemicals are usually not available at the right time. Plant resistance is therefore an attractive method of reducing stem borer damage.

The search for stem borer resistant varieties in Nigeria began in the early 1970s under the United States Agency for International Development (USAID) JP 26 project. Hundreds of sorghum lines from the world collection were screened over a 4-year period at Samaru using natural infestation. The entries were rated as R (resistant) if they had < 1 cm tunneling and evidence of larval mortality or abandonment; I (intermediate) if tunneling was 1-10 cm and there was evidence of larval mortality or abandonment; and S (susceptible) if the tunneling was > 10 cm and there was very little or no evidence of larval mortality (IAR 1976). On this basis, 22 varieties of the world collection and four improved varieties were rated as resistant. Of the 22 varieties, four were also reportedly resistant to shootfly (IS 6747, 6441,6449, and 8910).

In 1981 and 1982, MacFarlane (1984) screened 122 entries from ICRISAT and the Institute for Agricultural Research at Samaru, Nigeria. His parameters were percentage of stem tunneled, percentage internodes bored, and visual damage. Another set of 122 entries from an ICRISAT project in Kamboinse, Burkina Faso, is currently being screened at Samaru.

A number of observations can be made from these attempts to find sources of resistance to stem borers in sorghum. One observation is that borer infestation is highly variable from year-to-year, making interpretation of data difficult. Another is that the amount of leaf feeding is not a reliable parameter for measuring stem borer damage. This is probably because mixed infestations of *Sesamia* and *Busseola* usually occur and only *Busseola* feeds on the leaves. Also, there appears to be no correlation between tunnel length and grain yield.

It is clear that the methodology for evaluating stem borer nurseries needs to be perfected, preferably using laboratory-reared larvae to artificially infest nursery plants. To help accomplish this, an artificial diet was developed at Samaru composed of wheat, soyabean flour, brewers yeast, ascorbic acid, sorbic acid, formaldehyde, water, and agar. This diet yielded up to 60% pupation and adult emergence. Increasing the soybean flour content significantly improved the rate of adult emergence (Anonymous 1975).

Potential for Biological Control

Several parasitoids, predators, and disease organisms have been reported as natural enemies of sorghum stem borers in West Africa (Harris 1962, Gahukar 1981). According to Harris, *Tetrastichus atriclavus, Apanteles sesamiae,* and *Pediobius furvus* are always present on *B. fusca* towards the end of the growing season and are probably its most important parasites. *Bacillus thuringiensis* and *Aspergillus* spp are also found in or on the larvae and pupae of *B. fusca* at Samaru. The list of natural enemies will probably increase as more efforts are made to search for them. Although the overall rate of parasitism of stem borers is low and seldom exceeds 10%, the use of natural enemies for biological control appears to be worth pursuing. Meanwhile, there have been no studies on the population, ecology and efficiency of these natural enemies, nor have local staff been adequately trained on their utilization.

Chemical Control

Although the use of insecticides for sorghum stem borer control may be unattractive to the small farmer, the number of large-scale sorghum farmers who require and can afford insecticides is increasing, especially in Nigeria. A number of insecticides have been identified in field screening trials and can be recommended for use.

For the control of leaf-feeding stages of *B. fusca* carbaryl 85 WP; granular endosulfan 5G; and granular trichlorphon 5G applied into the whorl three times at weekly intervals have been recommended (Ajayi 1978, Adesiyun 1976). Granules of the systemic insecticide carbofuran, applied into the planting hole at planting, followed by a side dressing 6 weeks later, controls *Sesamia* and provides control of *Busseola* larvae which enter the stem at the base (IAR 1975, Ajayi 1987). Recent yield loss assessment trials using insecticides show that stem borer control, in the southern Guinea savanna where *Sesamia* predominates, improved yields by 16-19% (Abu 1986a). Similar stem borer control in the northern Guinea savanna, where *B. fusca* predominates, improved yield by 49% (Ajayi 1987). In both cases, the thick-stemmed sorghum variety SK 5912 was used. In trials at Samaru, in which several improved sorghum varieties were planted, the thin-stemmed varieties exhibited more severe damage than SK 5912 in terms of stem breakage, especially at the peduncle. It may be assumed, therefore, that stem borers will cause more yield reduction as more farmers adopt these improved, thin-stemmed varieties.

Requisites for Integrated Control

Various measures can be integrated and used in contribution to control stem borers. But there are a number of requisites before integration can be successfully employed. Some of the more obvious and pressing needs are listed below:

1. In order to refine the use of insecticides, the economic threshold level for each stem borer species and a complex of species needs to be determined.
2. To develop an effective biological control program, the biology, ecology, and efficiency of the identified natural enemies of the stem borers need to be studied.
3. There is a need to develop an accurate procedure for breeding and screening sorghum lines for resistance to stem borers. Laboratory rearing and screenhouse facilities, which are currently not available to sorghum researchers in West Africa, are important requisites.
4. A method of predicting outbreaks of sorghum stem borers is needed. Such a method should be amenable to use by individual farmers in view of the communication difficulties existing in West Africa. Pheromone trapping is a possibility.

5. Knowledge of the distribution of sorghum stem borers is still inadequate in some parts of West Africa. The only comprehensive studies seem to have been made in Nigeria (Harris 1962, Abu 1986a, b) and Burkina Faso (Nwanze 1985).
6. Effects of the changing cropping systems in some parts of West Africa, on the stem borer species complex and activity, needs to be elucidated. In Nigeria, for example, large farms of monocropped sorghum have been developed. Also, maize is fast replacing millet in some parts of the southern and northern Guinea savannas. In addition, wheat is being grown under irrigation during the dry season in the northernmost parts of the country and *Scsamia* is the only stem borer so far recorded on wheat (Ajayi 1986). The role of wheat in enhancing the survival of *Sesamia* during the dry season has not been studied.
7. The number of entomologists currently working on sorghum insects in the region is grossly inadequate, as is the level of research funding. There is an urgent need to strengthen sorghum research through national programs in the region.

Conclusion

The identification, distribution, and relative importance of stem borers of sorghum in West Africa have been studied. *Busseola fusca* and *Sesamia,* especially *S. calamistis,* are the major stem borers. *B. fusca* is more important in the northern Guinea savanna while *Sesamia* predominates in the wetter southern Guinea savanna, although there are pockets in the latter where *B. fusca* predominates. Control measures have been developed for both stem borers. These include the destruction of stems to kill the stem borer larvae, intercropping with millet, the use of stem-borer resistant varieties, and the application of insecticides. Many natural enemies of the stem borers have been identified but further studies are needed before they can be effectively used in biological control programs. It is desirable to integrate those measures that are compatible in order to attain economic control of the stem borers.

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Sorghum Stem Borers in Eastern Africa

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Abstract

Twelve stem borer species have been recorded on sorghum in eastern Africa. Chilo partellus, C. orichalcociliellus, Eldana saccharina, Busseola fusca, Sesamia calamistis, *and S.* cretica *are the most important. The distribution, biology, ecology, and grain yield losses caused by these stem borers and their management are discussed.*

Résumé

Les foreurs des tiges du sorgho en Afrique de l'Est : Douze espèces de foreurs des tiges ont été signalées sur sorgho en Afrique de l'Est. Les plus importantes sont : Chilo partellus, C. orichalcociliellus, Eldana saccharina, Busseola fusca, Sesamia Calamistis ***et*** S. cretica. ***La distribution, la biologie et l'écologie de ces foreurs ainsi que la baisse de rendement en grain due à ces ravageurs sont décrites. Des méthodes de lutte sont examinées.***

Introduction

In eastern Africa, sorghum *(Sorghum bicolor* [L.] Moench) is a traditional staple crop for millions of people. It is also grown as feed for poultry and livestock in the form of grain, forage, and fodder. A number of countries in the eastern African region are working on sorghum improvement including: Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. World production of sorghum grain totals approximately 63 million metric tonnes, produced on some 47 million hectares. In eastern Africa, where 12.5% of the world's acreage is under sorghum, grain yield is very low, with an average of 1090 kg ha^{-1}, compared with 3063 kg ha^{-1} in the USA (FAO 1984). One of the major constraints to production is insect pests.

Lepidopterous stem borers are the most widespread group of insect pests of sorghum in eastern Africa. On late-planted sorghum, infestations of these insects can cause substantial grain yield losses on small-scale farms. This paper briefly discusses the advances made in the studies on distribution, incidence, crop losses, biology, ecology, physiology, and the management of stem borers of sorghum in eastern African countries.

Distribution of Stem Borers

The wide range of lepidopterous stem borer species infesting sorghum in the region of eastern Africa is indicated in Table 1. However, the most notorius species in these countries are: *Chilo partellus, C. orichalcociliellus, Eldana saccharina, Busseola fusca, Sesamia calamistis* and *S. cretica.*

Although *C. partellus* occupies the low warm and humid areas of sorghum production, it has been recorded at an altitude of 1800 m, whereas *C. orichalcociliellus* is confined to coastal areas of Kenya and Tanzania. *B. fusca* occurs in mid-altitude and highland areas. In Ethiopia, the occurrence of *B. fusca* is relatively rare around 1200 m but its severity often intensifies during periods of relatively warm temperature. It usually phases out, with C. *partellus* and *S.calamistis* increasing in prominence

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Table 1. Stem borers of sorghum in eastern Africa[1].

Stem borer	Countries reporting the presence of borer
Chilo partellus (Swinhoe) (sorghum stem borer)	Ethiopia, Kenya, Somalia, Sudan, Tanzania, Uganda.
Chilo orichalcociliellus Strand (coastal stalk borer)	Kenya, Tanzania.
Eldana saccharina Walker (African sugarcane borer)	Burundi, Kenya, Rwanda Somalia, Tanzania, Uganda.
Ematheudes sp. nr. *helioderma*	Uganda.
Busseola fusca Fuller (maize stalk borer)	Burundi, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, Uganda.
Busseo la segeta Bowden	Tanzania, Uganda.
Sesamia calamistis Hampson (African pink stalk borer)	Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda.
Sesamia cretica Lederer	Ethiopia, Kenya, Somalia, Sudan.
Sesamia a/bivena Hampson	Burundi
Sesamia botanephaga Tarns & Bowden	Kenya, Sudan, Tanzania, Uganda
Sesamia penniseti Tarns & Bowden	Uganda
Sesamia poephaga Tarns & Bowden	Kenya, Tanzania, Uganda

1. Sources: Ingram 1958. Nye I960, Gebrekidan 1982. Seshu Reddy 1985a, and Seshu Reddy and Omolo 1985.

as altitude drops (Megenasa 1982). *E. saccharina* is considered to be the most important stem borer and a head pest of sorghum in Burundi (Kabiro 1982). In Somalia and Sudan both *C. partellus* and 5. *cretica* are serious (Alio 1986, and Farrag 1986).

Infestation and Losses

In western Kenya, it is rare to find healthy sorghum plants in many farmers' fields at harvest. Among the damaged plants, extent and density of stem borers vary. In studies conducted in farmers' fields, infestations of borer complexes *C. partellus, B. fusca. S. calamistis,* and *E. saccharina* ranged from 95-100%. Larval and pupal populations, measured per 40 plants, ranged widely: *C. partellus 0-14, B. fusca* 40-174, and *S. calamistis 0-34.* Generally, the population of *E. saccharina* was low, ranging from 0-2 per 40 plants. These four stem borer species were also found feeding on the same sorghum plant.

In Uganda, 56% grain yield losses occurred when sorghum was infested by *C. partellus at* 20 days after plant emergence (DAE) (Starks 1969). In field studies conducted at the ICIPE's Mbita Point Field Station in western Kenya, grain yield losses in sorghum caused by *C. partellus* reached 74.4% when plants were infested with 5 larvae/plant at 10 DAE. Losses were 87.8% when plants were infested with 10 larvae/plant, at 10 DAE. As plant development advanced, initial larval infestation caused lower yield losses, as low as 2-13% at 60 DAE. In research elsewhere in the region, in Tanzania, it was reported that *B. fusca* is typically found in sorghum at 40-100% infestation (Jepson 1954), and Megenasa (1982) reported that in Ethiopia, movement of *B. fusca* larvae into the base of the sorghum head resulted in undersized heads and a 15% grain loss.

Bionomics, Ecology, and Physiology

In eastern Africa, the biology and ecology of major stem borer species of sorghum have been studied by several workers (Jepson 1954, Ingram 1958, Nye 1960, Wheatley 1961, de Pury 1968, Schmutterer 1969, Mathez 1972, Bohlen 1973, Girling 1978, and Nur 1978).

In Kenya, field and laboratory investigations conducted on diapause associated with aestivation by larvae of *C. partellus* and *C. orichalcociliellus,* showed that while sufficient moisture was available for plant growth, development was continuous and the larvae had pigmented spots. On the cessation of rain or irrigation, the cuticular pigment was lost, and larvae became resistant to drought and ceased feeding. Temperature, relative humidity, and day length did not affect diapause, indicating that changes in the food-plant might be responsible (Scheltes 1978). However, inquiry into larval development showed that it was possible to rear *B. fusca* throughout the year on young sorghum stems without any intervening diapause, while feeding on mature stems induced diapause (G.C. Unnithan, personal communication). Preliminary electrophysiological tests on certain tarsal and ovipositor sensilla of adults of *C. partellus* and £. *saccharina,* showed that the sensilla were innervated by mechano- and contact- chemoreceptor cells. Tarsal receptors were sensitive to sucrose, whereas the oviposition sensilla were not (Waladde 1983).

Host Range

Several host plants of sorghum stem borers have been recorded and documented by various workers (Jepson 1954, Ingram 1958, Le Pelley 1959, and Nye 1960). Surveys to find various natural hosts of the sorghum stem borers were conducted in the environs of Lake Victoria in western Kenya. Several species of plants were found to harbor stem borers (Table 2). Of these plants, *B. fusca* damage was recorded as a percentage on several species: *Hyperrhenia rufa* (26%); *Pennisetum macrourum* (53%); *Phragmites mauritianus (34%);* and wild sorghum (49%). *Cyperus ariticulata* was identified as an important host of *E. saccharina,* with up to 42% plants damaged. *Sesamia* spp were found to infest *C. papyrus* (47%) and *Typha latifolia* (35%).

Table 2. Natural host plants of sorghum stem borers.

Host plant	*C. partellus*	*B.fusca*	*Sesamia* spp	*E. saccharina*
Cenchrus ciliaris	+[1]	–[2]	–	–
Echinochloa colonum	–	+	+	–
Echinochloa haploclada	+	-	+	–
Echinochloa pyramidalis	–	+	-	–
Hyperrhenia rufa	-	+	–	–
Leptuous repens	+	+	+	+
Panicum maximum	+	+	+	–
Pennisetum macrourum	+	+	–	–
Pennisetum purpureum	+	+	+	–
Phragmites mauritianus	–	+	+	–
Sorghum arundinaceum	+	+	+	–
Sorghum verticilliflorum	+	+	+	-
Sporobolus marginatus	+		-	–
Cyperus articulata	+	·	+	+
Cyperus papyrus	+	–	+	–
Kyllinga sp.	–	–	+	+
Typha latifolia	–	–	+	–
Launaea comma[3]	+	–	–	·

1. + = Recorded host.
2. - = Not recorded.
3. Only eggs were seen.

Control Methods

Cultural Control

Sowing Date

It has been found that early sowing of sorghum resulted in less infestation by stem borers than the late-planted crop in western Kenya. Destruction of crop residues, stubble, volunteer and alternate host plants have been suggested by different workers to reduce borer infestations (Duerden 1953, Jepson 1954, Ingram 1958, Nye 1960, Seshu Reddy 1985a, and Unnithan and Seshu Reddy 1986).

Intercropping

In Tanzania, Kato et al. (1982) observed that oviposition response of insect pests such as shoot fly and stem borers (C. *partellus, B. fusca,* and *S. calamistis)* was higher in sorghum monocrops than in mixed crops of sorghum and simsim. Also, fewer deadhearts were recorded in intercropped sorghum than in pure stands of maize.

In Kenya, Amoako-Atta et al. (1983) established that intercropping noncereal/cereal combinations delays *C. partellus* colonization and establishment processes. Early and late infestation, colonization. build-up, and establishment of stem borer complexes of C. *partellus, B. fusca, E. saccharina* and *S. calamistis* have also been related to different sorghum/cowpea/maize combinations (Omolo and Seshu Reddy 1985).

Fertilization

In Uganda, following nitrogen and phosphorus fertilizer applications, greater populations of C. *panel-*

lus were found in grain sorghum plots (Starks et al. 1971). In Sudan, Siddiq (1972) found that application of nitrogenous fertilizer to sorghum increased the infestation of *C. partellus* and *S. cretica.*

Plant Resistance

An important prerequisite for identifying sources and mechanisms of plant resistance to sorghum stem borers is the capacity for mass production of the borers themselves. A method of steady production of *C. partellus* has been established at the ICIPE, Kenya and an efficient, simple and easy method of collection of first-instar larvae from the incubation chamber has been developed (Ochieng et al. 1985).

Evaluation of sorghum for resistance to stem borers has been standardized using two categories of parameters: colonizing levels of insects on different cultivars; and degree of damage suffered by them. The parameters for the colonizing levels are: oviposition (percentage of eggs laid); and number of larvae/pupae per plant, or per 10 plants. Damage parameters include: the primary damage expressions, e.g., foliar lesions (visual rating on 1-5 or 1-9 scales); stem tunneling (percentage of stem length); deadheart (percentage of plants showing the symptom); and secondary damage expressions, e.g., stalk breakage and/ or head breakage (K.N. Saxena, personal communication).

In the Ethiopian sorghum improvement program nearly 6000 indigenous Ethiopian sorghum germplasm entries have been evaluated under hot spot natural infestation for their reactions to *B. fusca.* Barely 1% of the entries were rated tolerant. However, they were rated susceptible under more rigorous tests in subsequent seasons (Gebrekidan 1981). Seshu Reddy (1983 and 1985b), based on screening work in Kenya, reported several promising sources of resistance to sorghum stem borer complex. These include: IS nos. 1044, 1151,3962,4213,4405,5613, 10364, 10370, 10711, 12447, 18326, 18427, 18479, 18517, 18676, S-178, Tx 2780, and A & B Tx 2756. Based on the overall resistance and susceptibility index (ORSI, the ratio of each parameter value for a cultivar to that for the control), resistant sorghum cultivars include Tx 38, IS nos. 4660, 3962, 10370, 10711, and 4881. IS 1044 and S-178 were found to be highly resistant relative to the control IS 18520. The lower the ORSI value for a cultivar (<1.0) the greater its overall resistance (K.N. Saxena, personal communication).

Dabrowski and Kidiavai (1983) reported that a wide range of mechanisms were involved in *C. partellus* resistance in sorghum including nonpreference for oviposition, reduced feeding of the first-instars on young leaves, reduced tunneling activity of the first-instars on young leaves, reduced tunneling activity of older larval instars, and tolerance of plants both to leaf damage and stem tunneling. Morphological, physical and other plant characteristics, which are easily detectable and are of practical plant breeding value, need to be further studied to determine their contribution to resistance.

Studies on genetics of sorghum resistance to *C. partellus* in Kenya demonstrate that resistance is polygenically inherited, and partially dominant to susceptibility (Pathak and Olela 1983). In Uganda, Starks and Doggett (1970) made significant advances in both breeding methodologies and incorporation of resistance to *C. partellus.* Although several sources of sorghum resistance to stem borers are available in eastern Africa, little effort has been made to incorporate the resistance into high-yielding cultivars.

Biological Control

In eastern Africa, the role of natural enemies (parasitoids, predators, and pathogens) as a cause of population fluctuations in stem borers of sorghum has been investigated by several workers (Jepson 1954, Ingram 1958, Schmutterer 1969, Mohyuddin and Greathead 1970, Mathez 1972, Megenasa 1982, and Seshu Reddy 1983, 1985a).

In Kenya, three egg parasitoids (two scelionids and a trichogrammatid) caused up to 92% mortality in *Chilo* spp and 97% in 5. *calamistis.* Parasitism of larvae and pupae was usually below 10% although eight parasitoids were found together with a further six possible parasitoids (Mathez 1972). Mohyuddin (1972) suggested that *Dentichasmias busseolae.* a solitary pupal endoparasitoid (and one of the abundant and widely distributed parasitoids), could play a significant role in reduction of *C. partellus* populations in eastern Africa. Parasitism ranged from 6-58%. In western Kenya, parasitism of *C. partellus* by *D. busseolae* has been recorded at 11 weeks after plant emergence reaching a peak of 60% two weeks after. Incidence dropped to 15% at 14 weeks and again rose to a maximum of 70% at 16 weeks (J.W. Bahana personal communication).

Investigations in Uganda considered the possible biological control of *E. saccharina,* by the parasitic bethylid, *Parasierola* spp. A laboratory colony of the parasitoid was established on the larvae of *E. saccharina* in stems of sorghum. Up to 22 adult bethylids were produced from one host larva and the sex ratio was 7 females to 1 male. Larvae of *C. partellus, B. fusca,* and *S. calamistis* were not accepted as hosts but those of *C. partellus* were occasionally paralyzed and used as food in the absence of *E. saccharina* (Girling 1979). Releases of exotic parasitoids *Apanteles flavipes, Bracon chinensis, Isotima javensis, Trichogramma australicum,* and *Sturmiopsis inferens* against *B. fusca, S. calamistis, C. partellus,* and *E. saccharina* have not been successful in eastern Africa (Ingram 1983).

In western Kenya, stem borers are parasitized by the parasitoids *Trichogramma* spp., *Apanteles sesamiae, Pediobius furvus,* and *D. busseolae.* Production, development, sex ratio, and longevity of these parasitoids have been studied in the region. Also, techniques for mass culture of important parasitoids of sorghum stem borers have been initiated (G.W. Oloo, personal communication).

In Kenya, Mathez (1972) considered unidentified bacteria, viruses, and fungi the most important limiting factoh to larvae of *C. partellus, C. orichalcociliellus,* and *S. calamistis* in the field. Spore suspension application of a protozoan *Nosema* spp. to sorghum plants infested with first-instar *C. partellus* larvae, effectively controlled the borer. Also, application of a nematode, *Panagrolaimus* sp is being investigated as a tool in integrated management of sorghum stem borers (M.O. Odindo and W.A. Otieno, personal communication).

Information on the role of predators in stem borer control is scanty. However, in Kenya, earwigs *(Diaperasticuserythrocephala),* black ants *(Camponotus rufoglaucus),* lady bird beetles *(Cheilomenes* spp.), and spiders have been recorded as predators of the major stem borers of sorghum.

Chemical Control

In eastern Africa, several workers have used insecticides to control *B. fusca* under experimental conditions (Duerden 1953, Coaker 1956, Swaine 1957, Ingram 1958, Walker 1960, Schmutterer 1969, Mathez 1972, Bohlen 1973, and Assefa 1981). Chemical control of sorghum stem borers is expensive and has not proven to be economically feasible on subsistence farms. Other drawbacks to chemical control include the dangers of environmental pollution, the potential for pest resistance, and post-control pest resurgence.

Pheromone and Light Traps

Pheromone traps containing either synthetic or virgin females could be used in monitoring stem borer populations in the field. In western Kenya, mean catches/trap/night in pheromone traps with virgin females were highest for *Maliarpha separatella* (a rice stem borer) followed by *C. partellus and. B. fusca* (Ho and Seshu Reddy 1983). Further studies showed that *B. fusca* virgin females were more than two times as efficient as synthetic pheromones in attracting males, and mated females did not attract males. However, in *C. partellus,* traps containing virgin females attracted a much higher percentage of males (89%) than synthetic pheromone-baited (4%) or blank (7%) traps. Even after mating and oviposition, *C. partellus* females continued to attract males, although not as well as the virgin moths (*G.C.* Unnithan, personal communication).

Various factors which influence trap catches, and could be used to standardize trapping techniques, were also considered. It was observed that traps with *C. partellus* virgin females set 40 m apart attracted more males than those set 20 m apart. Virgin females reared on artificial diet attracted males as efficiently as those reared on natural diet (sorghum). The number of males trapped increased as the number of virgin females increased per trap, up to a maximum of 4 females/trap. The attractability of the virgin females declined with age (G.C. Unnithan, personal communication).

Preliminary studies conducted in western Kenya showed *M. separatellato* have the highest attraction to light traps, followed in descending order by *C. partellus, E. saccharina, S. calamistis,* and *B. fusca* (Ho and Seshu Reddy 1983).

Integrated Pest Management (IPM)

In Kenya, the main goal of the ICIPE Crop Pests Research Program is to develop ecologically acceptable management strategies to control sorghum stem borers. These strategies must also be economically and sociologically feasible for resource-poor, small-scale farmers in Africa and other developing countries. Components that are being developed for integrated management of stem borers belong to the following categories: plant resistance; intercropping of certain specific combinations of host and nonhost crops; other cultural practices such as sowing date, crop residues, disposal, etc; biological control, use of parasitoids and pathogens, and behavioral manipulation.

Conclusion

Stem borers are a major constraint in sorghum production in eastern Africa. There is a long history of interaction between various species of stem borers and sorghum, especially with *C. partellus, C. orichalcoclliellus, B. fusca, S. calamistis, S. cretica,* and *E. saccharina.* Development of borer-resistant sorghum cultivars, use of efficient natural enemies, and cultural control practices could contribute substantially to the management of these stem borers under subsistence agriculture. Although sources of sorghum resistance to stem borers are available in the region, little progress has been made in incorporating resistant genes into agronomically elite materials. Host-plant resistance will have to play a greater role than it has in the past. Cultural practices such as intercropping sorghum with nonhosts, field sanitation, and adjustment of sowing dates could play a significant role in reducing yield losses caused by stem borers.

As Ingram (1983) suggested, although some effective parasitoids have already been identified, critical ecological studies are required to pinpoint more precisely where the addition of further parasitoid species are most likely to be effective. Such studies should assess the role of stem borers and parasitoids in wild host plants in relation to: dry seasons; crop infestations; relative effectiveness of egg, larval, and pupal parasitoids; the effect of predators and pathogens; and possible changes in agronomic practice to enhance the effectiveness of natural enemies. Such studies could contribute to a more effective program of introductions, mass rearing, and large-scale releases of the natural enemies. Very little is known about stem borer predation other than the occasional references to black ants, earwigs, coccinellid beetles and spiders attacking eggs and early larval instars. Similarly, the role of pathogens such as protozoan *Nosema,* fungi, bacteria, and nematodes should be explored in traditional small-scale and peasant farms. Hence, there is much need for the development of environmentally safe, economically and sociologically acceptable management strategies for the stem borers of sorghum, not only in eastern Africa but throughout the tropical world.

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Sorghum Stem Borers in Southern Africa

S.Z. Sithole'

Abstract

*The four stem borers attacking sorghum in southern Africa are the spotted stem borer (*Chilo partellus *Swin), which is the most important, maize stalk borer (*Busseola fusca *Fuller), pink stem borer* (Sesamia calamistis *Hmps), and sugarcane stem borer (*Eldana saccharina *Wlk).*

Control strategies include the use of cultural and chemical methods with little or no use of bioagents and resistant genotypes. Moth migration has been identified as an important bionomic factor. Thus, synthetic pheromones have an important role to play in integrated stem borer management. Current research activities are geared towards the use of resistant sorghum genotypes, defining the extent of sorghum stem borer infestations and their subsequent translation into yield losses.

Résumé

Les foreurs des tiges du sorgho en Afrique australe : *Les quatre espèces de foreurs des tiges nuisibles au sorgho en Afrique australe sont le borer ponctué du sorgho (*Chilo partellus*) qui est l'espèce la plus importante, le foreur africain du maïs (*Busseola fusca*), le borer rose africain (*Sesamia calamistis*) et le borer africain de la canne à sucre (*Eldana saccharina*).*

Les stratégies de lutte reposent sur les méthodes culturales et chimiques qui utilisent peu ou pas d'agents biologiques et de génotypes résistants. La migration des adultes est considérée comme un important facteur écologique. L'utilisation de phéromones de synthèse est donc un élément important dans la lutte intégrée contre les foreurs. Les recherches sont actuellement axées sur l'exploitation de génotypes résistants, l'évaluation des niveaux d'infestation des foreurs et leur traduction en chute de rendements.

Introduction

In southern Africa, grain sorghums are grown primarily for human consumption. Surpluses are used for feeding different classes of livestock (Sibanda 1985). Grain yields from fields of resource poor farmers are low, ranging from 600 to 900 kg ha^{-1}. One of the major constraints responsible for low yields is insect pests (Seshu Reddy 1982).

Stem borers have proven to be the most economically important insect pests of sorghum and maize in southern Africa (Blair 1971, van Rensburg et al. 1978, van Hamburg 1976,1979,1980, van Rensburg 1980, van Rensburg and Malan 1982, Sam et al. 1985, Sithole 1986, van Rensburg et al. 1987, Skoroszwski and Van Hamburg 1987). The maize stalkborer (*B. fusca*), spotted stem borer (C. *partellus),* pink stem borer (*S. calamistis),* and (E. *saccharina*) constitute the most economically important group of insect pests of sorghum. Under heavy infestation, these borers are capable of rendering a whole crop of sorghum useless. The relative importance of these stem borers in the subregion varies from one agroecological region to another. Infestations range from 30-70% in subsistence farmers' fields but average less than 30% on commercial farms. To date, no

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sorghum yield-loss studies have been conducted in southern Africa, but current research in Zimbabwe seeks to quantify the impact of stem borers on sorghum yield. Current research activities in sorghum entomology in the subregion are directed toward gaining information on stem borer migration, and developing control measures through timely use of insecticides, cultural practices, biocontrol agents, sex pheromones, and resistant sorghum varieties.

Damage and Yield Losses

Busseola fusca, C. partellus, and *E. saccharina* produce more or less similar damage symptoms in sorghum and maize plants. Newly hatched larvae migrate from oviposition sites to feed on rolled developing leaves. After a few days, the leaves unroll to reveal characteristic patterns of small holes, resembling hail damage, which are inflicted by the feeding larvae. As the larvae mature within the plant funnels, they attack different parts, boring into the stem below the funnel leaves. Once established inside the stem, larvae are protected and are much less vulnerable to insecticides and natural enemies. The larvae feed and tunnel inside the stems and prior to pupation, cut exit holes, through which the moths emerge. This exit is often seen covered by a thin 'membrane' of stem tissue. Stem-tunneling weakens the stem, interferes with the translocation of metabolites and nutrients within the plant, resulting in malformation of grain. Other symptoms associated with stem borer attack are deadhearts, stem or peduncle breakage, and stunted growth of the whole plant.

Damage symptoms ascribed to *S. calamistis* attack may be distinguished from those due to *B. fusca* and *C. partellus* in several ways. In *S. calamistis,* the central leaves wither and turn brown, and increased tillering is initiated. No feeding marks are found on the leaves but an external borer-hole may be found near soil level at the base of the stem. Walters et al. (1980) and Van Rensburg (1981) described loss of maize yield due to *B. fusca* as 'tremendous' while Revington (1986) estimated losses due to *C. partellus* to be more than 50% in the highlands. Recent work by the author (unpublished) indicated that loss in sorghum yield can range from 50-60% due to *C. partellus.*

Distribution and Biology

Spotted Stemborer, *C. partellus*

Chilo partellus invaded the African content from India (Mohyuddin and Greathead 1970). It was first reported in South Africa in 1958 (van Hamburg 1979). It is the most important sorghum stem borer in the subregion. Although it may cause severe losses in maize, *C. partellus* prefers sorghum as its food plant. Unpublished work by Berger has indicated that *C. partellus has* 3 or more generations in southern Mozambique, especially where maize is grown throughout the year (Fig. 1). First generation moths emerge with the onset of the rainy season from September to November, and lay eggs on leaves of the

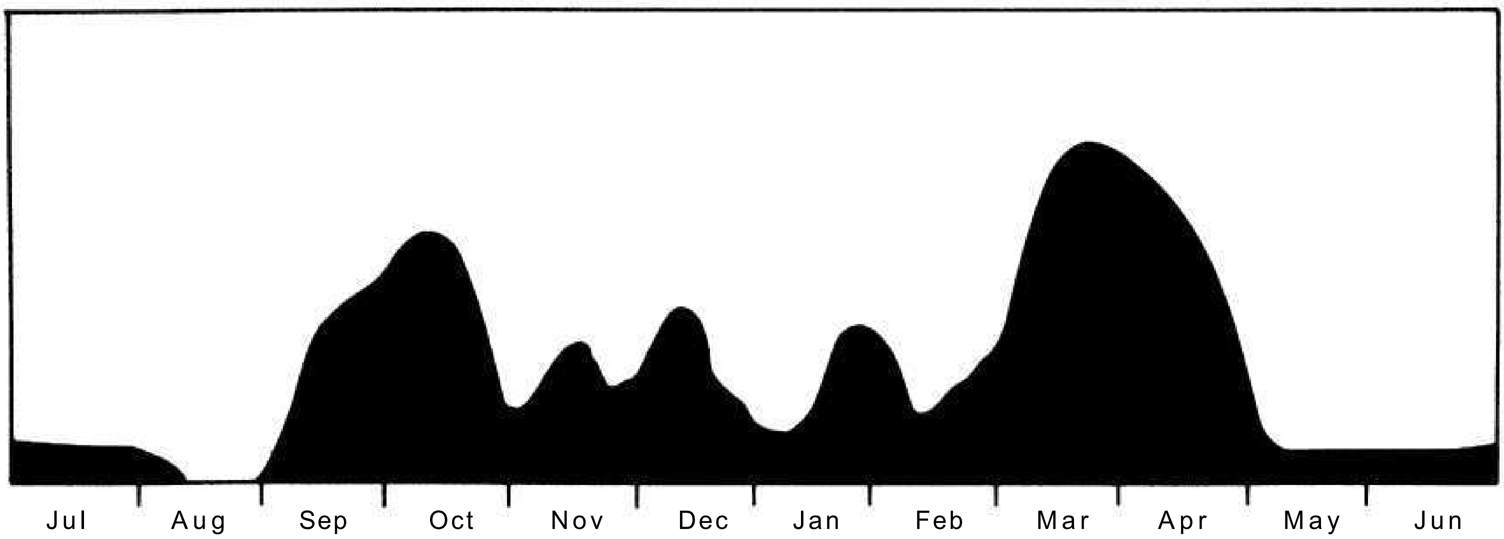

Figure 1. Seasonal changes in the number of moths of *Chilo partellus* during the year.

early plantings of maize and sorghum. Newly hatched larvae attach themselves to leaves by spinning-off thin silk threads, and are launched into the air by the wind to infest neighboring plants (Berger, personal communication, Revington 1986). Revington has described this as an instinctive dispersal mechanism, serving to reduce competition between larvae that hatch from the same egg batch and thereby increase their survival chances. The same indications have been given by van Rensburg and van Hamburg (1975) and Van Hamburg (1979, 1980) in South Africa, Berger (personal communication) in Mozambique and Chapman et al. (1983) in India. Investigations on this dispersal ability, in southern Africa, has shown a decline with increase in age of the larvae.

Maize Stalkborer, *B. fusca*

This is the second most important sorghum borer in the subregion, and among the insect pests of maize *B. fusca* is generally regarded as the most economically important pest (Annecke and Moran 1982). *Busseola fusca* is indigenous to southern Africa and prefers maize as a host plant but causes serious losses to grain sorghum (Skoroszewski and van Hamburg 1987).

Figure 2 summarizes the life-cycle of *B. fusca.* van Rensburg et al. (1987) reported on the ecology of *B. fusca* and recommend that the monitoring of *B. fusca* infestations be conducted between 3- and 6-weeks after the emergence of the maize crop in order to determine the correct timing of chemical control measures.

Busseola fusca is the dominant stem borer species of sorghum at high elevations in southern Africa (Table 1). However, this author has observed high infestations of the pest on sorghum even at low elevations in Zimbabwe, where very low infestations would be expected. Clearly, this shows the capability of the pest to adapt itself to low-lying and warmer areas. *Busseola fusca* has two generations per year but in some seasons a third generation may appear, depending on prevalent environmental conditions and the availability of suitable host plants. At the onset of the dry season, second generation larvae enter into diapause in tunnels at the bases of drying sorghum stems. These larvae pupate later, in about mid-October, with the arrival of summer rains. Moths emerge three weeks later. The moths lay eggs on the bases of leaf sheaths. The eggs take about a week to hatch and the newly hatched larvae migrate to feed on tender leaves in the funnel before boring into the stem. Unpublished results of investigations into larval migration in Zimbabwe have indicated that migration is density-dependent. Peak migratory activity was observed among second generation larvae. The development of larvae and pupae lasts about 2 months. The emergence of second-generation moths reaches a peak during the period from mid-February to March (Fig. 2). Larvae which fail to attain full development prior to the onset of the dry season enter into diapause and pupate with the arrival of the summer rains. In September, the weather warms up and with available sorghum or maize under irrigation, the diapausing larvae pupate and third generation moths emerge later.

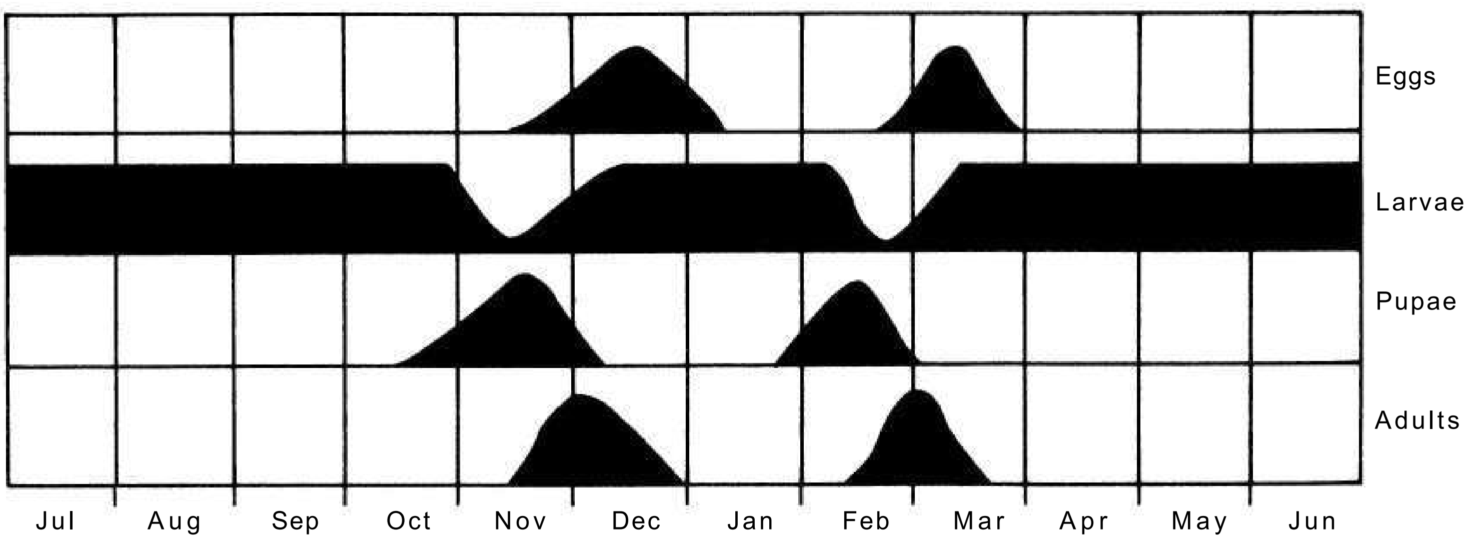

Figure 2. Seasonal changes in the occurrence of different stages of *Busseola fusca* during the year (modified after Blair 1971).

Table 1. Distribution of lepidopterous stem borer of sorghum in southern Africa.

Stem borer				Elevation (m) and percentage relative abundance[1]		
Common name	Scientific name	Country	Economic importance rank[2]	High >900	Medium 700-900	Low <700
Spotted stem borer	*Chilo partellus* (pyralidae)	Botswana	1	5	40	70
		Malawi	1			
		Mozambique	1			
		South Africa	1			
		Swaziland	2			
		Zimbabwe	1			
Maize stalkborer	*Busseola fusca* (Noctuidae)	Botswana	2	90	18	10
		Lesotho	1			
		Malawi	2			
		Mozambique	2			
		South Africa	2			
		Swaziland	1			
		Zimbabwe				
Pink stem borer	*Sesamia calamistis* (Noctuidae)	Malawi	3	5	40	10
		Mozambique	3			
		South Africa	3			
		Zimbabwe	3			
Sugarcane stem borer	*Eldana saccharina* (Pyralidae)	Mozambique	4	0	2	10
		South Africa	4			
		Swaziland	4			
		Zimbabwe	4			

1. Information arising from an investigation conducted by theauthorduring the 1985/86 cropping season. Percentage relative abundance is inclusive of all countries in the region which have distribution of the corresponding borers noted on this table.
2. Rank scale of 1 -5. where 1 = highest and 5 = lowest economic importance.

Pink Stem Borer *Sesamia calamistis*

The pink stem borer, 5. *calamistis,* attacks sorghum in Malawi, Mozambique, South Africa, and Zimbabwe. It is most prevalent at medium elevations (Table 1). *Sesamia calamistis* is unique in that its feeding habits are different from those of *B. fusca* and *C. partellus.* No feeding marks are found on the leaves of the host plant, but external borer-holes may be noticed near ground-level in the base of the stems. Central leaves wither and turn brown and suckers are produced. In southern Africa, very little research has been done on this pest, which is of little consequence to sorghum yield. Female moths have been observed laying eggs between the base of the leaf sheath and the main stem. Larvae hatch within a week and bore into the stem close to the oviposition site. Development is completed in the stem after about 6-10 weeks. The pupal period lasts for 2 weeks after which the moths emerge. Two generations of the pest have been observed in a year by the author.

Sugarcane Stem Borer, *Eldana saccharins*

The pyralid, *E. saccharina* Walker, is an important pest of sugarcane in southern Africa and hence the common name sugarcane stem borer (Atkinson 1982). It occurs in Mozambique, South Africa, Swaziland, and Zimbabwe (Table 1). It has become a serious pest of sugarcane in recent times in the coastal sugarcane-growing areas of Natal, in South Africa, and the southeastern part of Zimbabwe. Although it is known to attack maize and sorghum in the subregion, *E. saccharina* appears to be of very little importance in maize and sorghum production. Newly hatched larvae feed on leaves and bore into the stem when they are fully grown. The larvae spin off silken threads by which they hang down from plants and are blown by wind to neighboring plants. The larval period lasts for about 3-8 weeks after which pupation, lasting 1-2 weeks, commences inside the stem. Female moths lay up to 200 eggs.

Control of Sorghum Stem Borers

Chemical Control

Evaluation of insecticides for the control of sorghum stem borers has received considerable attention from entomologists in southern Africa, in recent years. Chemical control measures against grain sorghum stem borers are based on the use of contact and systemic insecticides, as spray or dust treatments to the foliage. However, significant control results have been achieved in the subregion with carbofuran 10% granules at 1 or 2 kg a.i. ha^{-1} (Walters and Drinkwater 1975, van Rensburg 1980, and van Rensburg and Malan 1982). Other insecticides in use include carbaryl, endosulfan, trichlorfon, and synthetic pyrethroids. These insecticides have been screened in different sorghum localities and the ones identified as being the most effective have been released to farmers through the extension service. The profit margin for sorghum is currently very low with the result that resource-poor farmers often cannot afford to spray against sorghum stem borers. It is therefore not surprising that the use of insecticides by these farmers is not widely practiced. Consequently, the use of insecticides for the control of sorghum stem borers is more or less restricted to large-scale and government-comrolled farms. Apart from the evaluation of insecticides for their effectiveness against stem borers, some work is now being done to find out the appropriate methodologies and timing of insecticide application, with a view to reducing the frequency and thus the cost of application.

In a drive to protect maize from C *partellus* damage, the current recommendation is to start spraying 10-14 days after crop emergence (DAE), or from the two-leaf to four-leaf stage with the initial spray applied within 21 DAE(Revington 1986). Similar studies by Sithole (unpublished) of the C. *partellus* on sorghum gave more or less similar results, and it has been recommended to spray during the period between 15 and 30 DAE.

Cultural Control

Theoretically, there are several cultural measures that could adversely affect stem borer population in a sorghum field. However, the practicality and the success of some of these measures as permanent control tactics are questionable. Such measures as early and simultaneous planting, disposal of sorghum residues by burning, or burial by deep plowing during the off-season, removal and destruction of volunteer and alternative host plants, and crop rotation are helpful in reducing stem borer infestations and their impact on yield. Intercropping has long been practiced by subsistence farmers, but little research attention has been given to this aspect in southern Africa.

Host-plant Resistance

The use of resistant -varieties is, by far, the most promising control measure in reducing yield losses caused by stem borers. Although this type of control is recognized to be economical and environmentally safe, the use of resistant varieties is very limited as no research work has been done on varietal resistance in southern Africa. The existence of the Southern African Development Coordination Conference (SADCC)-ICRISAT Program to improve sorghum and millet production in the subregion, has spearheaded the current screening of sorghum germplasm for resistance to stemborers.

Biological Control

A number of parasites and predators of sorghum stem borers have been recorded but very few studies on their effectiveness, as well as host/parasite relationships, have been conducted. Although the role of predators is not easy to assess, ants, spiders, mites, and reduviids are often encountered close to cadavers of stem borer larvae. Entomologists in southern Africa have shown interest in the use of biocontrol agents in controlling stem borers of maize and sorghum. Biocontrol agents of interest in the subregion include egg parasitoids such as *Trichogramma* sp (Trichgrammatidae), larval parasitoids including *Apanteles sesamiae* Cam. (Braconidae), and pupal parasitoids, e.g. *Dentichasmias busseolae* Heinrich (Ichneumonidae), and *Pediobius furvus (Gah.)* (Eulophidae). Skoroszewski and van Hamburg (1987) investigated the possibility of controlling *B. fusca* and *C. partellus* using an introduced larval parasitoid, *Apanteks flavipes* (Cameron). In Mozambique, work on *C. partellus* (Goncalves 1970) revealed the importance of *Trichoramma* sp in parasitizing eggs, and *A. sesamiae* in parasitizing larvae. Berger (1981) recorded *D. busseolae* Heinrich, *P. furvus Gah.* and *Lepidoscelio sp.* (Scelionidae) as parasites of pupae reaching levels of 10 14% parasitism. However, it should be noted that the level of parasitism by these parasites is generally low under natural conditions.

In southern Africa, Blair (1969), and Hall et al. (1981), discussed the effectiveness of a female sex-pheromone obtained from the 8th and 9th abdominal segments of *B. fusca* in controlling the pest. The effective pheromone has been characterized and synthetic pheromones tested under field conditions. Control of the pest is achieved by incorporating the pheromone as a bait in traps or in general application to confuse the male moths, which are then either killed or sterilized by chemical means. Since females mating with sterile males produce no progeny, the pest population can successfully be reduced to a subeconomic damage level.

Conclusions

Scientists interested in increasing sorghum production in southern Africa need to put more research efforts on the following: distribution, biology, and behavior of stem borer species; use of sex pheromones for monitoring adult populations; use of resistant sorghum cultivars; and formulating and implementing integrated and location-specific stern borer management program. In addition, yield loss investigations need to be conducted at research stations and on farmers' fields to generate information for devising stem borer control strategies.

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Sorghum Stem Borers in Central and South America

R. Reyes[1]

Abstract

This paper presents a literature review of the two major sorghum stem borers in Central and South America: Diatraea lineolata *Walker and* Diatraea saccharalis *Fab. Their importance, distribution, seasonal abundance, host plants, and life cycles are discussed. Control measures that are currently practiced (cultural, biological, and chemical) are also presented.*

Résumé

***Les foreurs des tiges du sorgho en Amérique centrale et du Sud :** Cet article présente une synthèse bibliographique sur les deux principaux foreurs des tiges en Amérique centrale et du Sud :* Diatraea lineolata *et* Diatraea saccharalis. *Leur importance, leur distribution, leur abondance saisonnière, leurs plantes hôtes et leurs cycles biologiques sont étudiés. Les mesures de lutte actuellement appliquées, telles que les méthodes culturales, biologiques et chimiques, sont également présentées.*

Introduction

Sorghum *Sorghum bicolor (L.)* Moench is one of the most widely grown cereal crops in Central and South America (Table 1). In 1985, approximately 3.2 million ha were harvested with a grain yield of about 8.5 million tonnes with 73% of production coming from Argentina. Grain yield ranged from 0.714 4.75 t ha^{-1} (FAO 1986, p. 121). In some countries, low-resource farmers grow native sorghums, intercropped mainly with maize, *Zea mays* L., producing low sorghum grain yields (Paul and de Walt 1985, and CAT1E[2] 1986). In contrast, when improved sorghum varieties are grown commercially in mechanized monoculture, with higher inputs, yields increase substantially (Juarez and Valdez 1978, and CENTA 1980).

Sorghum is used mainly for animal feed, in concentrates and as fodder. It is also grown for human consumption and in Brazil it is commercially grown for alcohol production (Bertels 1982a, Paul and de Walt 1985, and Pereira et al. 1987).

Mihm (1984) pointed out that the complex *Diatraea* spp. is the most important group of stem borers that attack maize, sorghum, and sugarcane *Saccharum officinarum.* Harris (1985) noted that different species of pyralid sorghum stem borers have been recorded: *D. lineolata* Walk., *D. saccharalis* Fab., *D. crambidoides* Grote, and *Elasmopalpus lignosellus* Zeller. Since these borers are considered occasional or minor pests, research on them in relation to sorghum has been limited.

Most of the work on stem borers has been conducted on sugarcane and maize, influencing this review to include information on these crops. The species infesting maize and sorghum in Central and South America are common to most countries of the region (Seshu Reddy 1985). Mendonca (1986) and

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Table 1. Sorghum grain production in Central America, Antilles, and South America during 1985[1].

Country	Area harvested ('000) ha)	Production ('000 t)	Yield (t ha^{-1})
Central America	330	523	1.63
Guatemala	66	89	1.35
El Salvador	116	139	1.20
Honduras	48	50	1.04
Nicaragua	74	194	2.61
Costa Rica	26	51	1.95
Antilles	140	130	1.36
Cuba	1F[2]	1F	1.10
Dominican Republic	17	52	3.02
Haiti	120[3]	75	0.62
Neth Antille	2E	2E	0.71
South America	2 725	7 796	2.60
Colombia	207	537	2.60
Venezuela	305[3]	590	1.93
Ecuador	3[3]	12[3]	3.57
Peru	5	23	4.75
Brazil	163	258	1.58
Bolivia	7	14	2.01
Paraguay	7F	I0E	1.43
U ruguay	63	152	2.40
Argentina	I 965	6 200	3.15

1. FAO 1985.
2. F = FAO estimate.
3. Unofficial figure.

Peairs and Saunders (1980) have reviewed stem borers on sugarcane and maize, while Teetes et al. (1980), Harris (1985), and Seshu Reddy (1985), provide a review of these insects on sorghum.

According to several studies (Obando 1975, Sequeira et al. 1976, Sequeira et al. 1986, and Reyes et al. 1987) the neotropical corn stalk borer (NCB) *D. lineolata* Walk is the most important sorghum stem borer in Central America. In South America, however, the most important stem borer is the sugarcane borer (SCB), *D. saccharalis* Fab. (Geraud 1970, Ruiz and Koritkowski 1975, Bertels 1982a, and Viana 1985). Given the many similarities between the two species, the present review will not deal independently on each borer but will relate and share topical information relating to these borers in common.

Sugarcane Borer *(Diatraea saccharalis* Fabricius) Neotropical Cornstalk Borer *(D. lineolata* Walker)

Distribution

Diatraea spp. occur only on the American continent. SCB is the most widely distributed species of the genus. It is found from southern North America, Central America, and the Antilles south to Argentina in South America (Fig. 1) NCB, the second most widely distributed borer, ranges from Central America and the Antilles to northern South America, including Colombia, Venezuela, Guianas, and Ecuador. NCB was first recorded from Venezuela in 1856 (Bleszynsky 1969, Peairs and Saunders 1980, King and Saunders 1984, and Harris 1985). In addition, NCB has been reported in North America, western and northern Mexico, and south Texas, U.S.A. (Box 1949, Hodges 1983, and Youm 1984).

Host Plants

NCB is more limited in its host range than is SCB; the latter is considered polyphagous. Myers, cited by Peairs and Saunders (1980) affirms that originally, SCB was in the riversides and that its primitive hosts were likely aquatic or semiaquatic grasses such as Paspalum, Echinochloa, Leptochloa, and Hymenachne. NCB and SCB attack crops of economic importance such as sugarcane, maize, sorghurn (sweet sorghum, and broom corn), wheat, and rice. Table 2 lists additional host plants (Jepson 1954. Requena and Angeles 1966, and Peairs and Saunders 1980). According to Quintana and Walker (1970) in Puerto Rico, the preferred hosts, for ovipositing and development of SCB young larvae were maize, sugarcane, sorghum, *Euchlaena mexicana,* and *Coixlachryma-jobi.*

Life Cycle

The life cycles of the NCB and SCB are very similar. In Central America work has been carried out on maize by Sequeira et al. (1976) and King and Saunders (1984) on the different development stages. Egg masses of 1-13 eggs are laid in juxtaposed files at both sides of the top leaves, appearing yellow as a scale (Obando 1975). Larvae hatch about 30 days, or

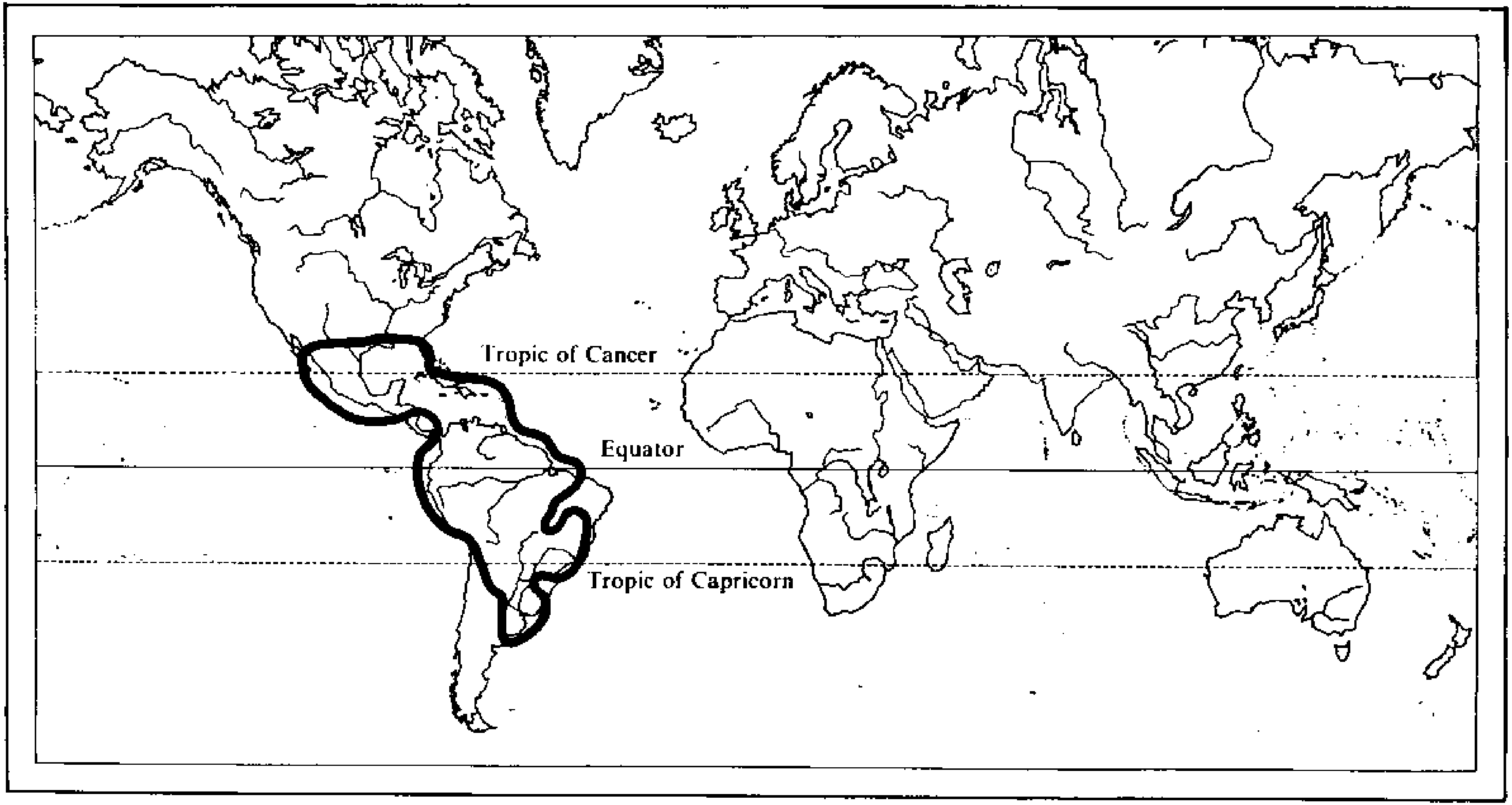

Figure 1. Distribution of sugarcane borer, *Diatraea saccharalis* (Fabr.) in North, Central, and South America, and the Antilles. (Reprinted with permission from the Commonwealth Institute of Entomology).

Table 2. Some host plants of *Diatraea saccharalis* Fab. reported in the Antilles, Central and South America.[1]

Host plant	Common name	Location
Axonopus compressus	Bermuda grass	West Indies
Coix lachryma-jobi	Job's tears	West Indies, Puerto Rico
Curcuma longa	Turmeric	Venezuela
Cymbopogon schoenanthus	Lemon grass	Cuba
Cyperus ligularis	Nut grass	Venezuela
Echinochola colonum	-	Cuba
E. polystacha	-	British Guiana, Venezuela
Eleusine indica	Goose grass	Cuba
Euchlaena mexicana	-	Puerto Rico
Sorghum sudanense	Sudan grass	Cuba
S. halepense	Johnson grass	Cuba
Hymenachne amplexicaulis	-	Orinoco delta
H. donacifolia	-	Haiti, British Guiana
Leptochloa virgata	-	Cuba
L. scabra	-	Puerto Rico
Oriza latifolia	Wild rice	Venezuela
O. sativa	Rice	Argentina
Panicum elephantipes	-	South America
Paspalidium geminatum	-	Haiti
Panicum grande	-	Venezuela
Paspaium fasciculatum	Tall grass	Venezuela
P. virgatum	-	Puerto Rico
P. repens	-	British Guiana, Orinoco
Pennisetum purpureum	Napier grass	Puerto Rico
Saccharum oficinarum	Sugarcane	South America
Tricholaena rosea	Natal grass	Cuba
Valota insularis	Sour grass	Cuba
lea mays	Maize, corn	South America

1. Sources: Jepson 1954, Requena and Angeles 1966. and Peairs and Saunders 1980.

100-150 days in diapause. The larva undergoes seven instars and measures 20-25 mm in length when mature. Young larvae feed on tender leaves for 2-3 days after hatching, before entering the stem. Usually they enter between the leaf sheath in the superior part of the plant, then bore into the stem, removing frass from the tunnel, and making one or more holes to the exterior. At the end of the season, in response to the quality deterioration of the food, some mature larvae undergo a prolonged period of resting (facultative diapause). This lasts for the remainder of the dry season, as the larvae settle in the bottom part of the dry stem without pupating, until rains start again.

In E1 Salvador, Quezada (1979) found 21% of larvae diapausing, of which 5% died due to desiccation or attack by entomopathogenes. Likewise, Reyes et al. (1987) recorded 22% of diapausing larvae on native sorghum. Larvae pupate in the stem close to an exit hole and pupal period lasts for 7-12 days. Pupae are brown with two pointed protuberances in the head, like horns, which are longer in SCB than in NCB. Adults live for 4 days, and develop a maximum wing expanse of 20-42 mm. SCB has a diagonal file of brown dots more or less defined in the forewings, but identification must be confirmed by examining the genitalia (Bleszynski 1969). The life cycle from egg to adult can last from 45-165 days, depending upon the diapause period. Quezada (1979) suggested 3-4 generations could be completed per year.

In Sao Paulo, Brazil, Bertels (1982a) indicated that each SCB egg mass can have from 30-40 eggs, and a female can lay up to 600 eggs during its life. The life cycle of SCB largely depends on the time of year, as well as temperature and humidity. In winter, larval instars can last up to 3 months due to low temperatures and high humidity. In Rio Grande do Sul, Brazil, and probably also in Uruguay, there are 4-5 annual generations. In the tropical regions of

Venezuela, this number increases significantly. High humidity is unfavorable to spring generations, which greatly reduces summer attack.

Damage

Damage inflicted to sorghum crops depends on the development of the plants. Improved sorghum varieties are susceptible to borer attack from 25-30 days after emergence (DAE). The larva tunnels into the stem killing the growing point, producing deadhearts, a symptom that may also result from attack by *E. lignosellus* and termites (Termitidae: Isoptera). This condition can produce loss of plant stand or delayed maturity because of tiller production. However, if young plants are seriously attacked, the whole plant may dry up. If the top internode is bored after floral differentation and before head emergence, the top leaves may dry up, and the emerged head could be completely empty. If the damage occurs during or after head emergence, it can result in partially filled heads. Generally, this damage occurs after the sorghum plants have flowered and is found in very localized areas within a plantation.

Busoli et al. (1979) in Brazil, and Reyes et al. (1983) in E1 Salvador, reported up to 48% of infested plants in improved sorghum varieties. Lodging and attack by microorganisms, such as *Colletotrichum* sp. and *Fusarium* sp., are favored by stem borer damage (Geraud 1970, Reyes et al. 1983, and Harris 1985). Losses due to stem borers are generally difficult to assess precisely. The number of pest species involved, the different types of damage, the plant developmental stages attacked, and often the presence of other insects and microorganisms have made it difficult to determine their effect on yield (Seshu Reddy 1985).

Seasonal Abundance

In Central America, sorghum planted in August is attacked more than sorghum planted in May because *Diatraea* populations increase from October to December (Sequeira et al. 1976, Lacayo 1977, and Cortez et al. 1984). In maize/ sorghum cropping systems, sorghum is damaged more due to high insect populations in October and November. Major infestations in maize and sorghum are more likely to occur from flowering to grain filling, with 19% average infestation (Sequeira et al. 1986, and Reyes et al. 1987). This might explain the lack of awareness that farmers have concerning the pest and its influence on grain production (Obando and Van Huis 1977). Observations made by Harris (1985) suggest that attack at harvest is highest on high-yielding plants, possibly as a result of preferential oviposition by female moths on superior plants.

In South America, Busoli et al. (1979) in Sao Paulo, Brazil, found that SCB in sorghum reached peak infestation in May, whereas in Rio de Janeiro, Pereira et al. (1987) affirm that sorghum planted in October and November is most affected. In Peru, Simon and Arellano (1959) reported that stem borer damage is more intense in the summer than in the spring.

Host-plant Resistance

In Brazil, the sweet sorghums BR 501, BR 504, and BR 505 have good levels of SCB resistance (Amaral et al. 1980, and Pereira et al. 1987). In addition, sorghum AF 28, which is also resistant to sorghum midge *Contarinia sorghicola* Coq., showed levels of 13% infestation, and sorghum EA 177, 26% infestation (Lara et al. 1979).

Cultural Control

Poor farmers from Central America usually feed their cattle maize and sorghum stubble during the dry season, which helps to reduce the diapausing larvae populations (Quezada 1979, and CATIE 1986). Several other cultural control measures have been suggested: destruction of stubble 1-2 months before the onset of the rainy season; gathering and burning of stubble, or incorporating it by plowing or disking; early sowing; early-maturing varieties; crop rotation (alternating *Gramineae* with *Leguminosae);* appropriate fertilization; and plant density to favor plant vigor (Sequeira et al. 1976, Cortez et al. 1984, and King and Saunders 1984).

Biological Control

The number of SCB and NCB natural enemies is large and complex. Many have been recorded in SCB in sugarcane, maize, and sorghum. Tables 3 and 4 list some biocontrol agents reviewed by several authors. Jepson (1954) has also reviewed biological information on natural enemies of stem borers in considerable detail.

Table 3. Distribution of egg and larva parasitoids of *Diatraea saccharalis* (Fab.) and *D. lineolata* (Walk.) reported in Central America (C), Antilles (A), and South America (S).

Parasitoids	Family : Order	Distribution	Reference
Egg			
Trkhogramma parasitoids			
Minutum Riley	Trichogrammatidae : Hym.	C A, S	Teetes et al. 1980
T. austratkum Gir.	Trichogrammatidae : Hym.	A, S	Teetes et al. 1980
T. fascia turn Perk.	Trichogrammatidae : Hym.	S	Sarmiento 1981
T. brasiliensis	Trichogrammatidae : Hym.	S	Sarmiento 1981
Trkhogramma sp.	Trichogrammatidae : Hym.	C	King and Saunders 1984
Teienomus alecto Cram.	Scelionidae : Hym.	C, S	Teetes et al. 1980
Larva parasitoids			
Lixophaga diatraea Tnz.	Tachinidae : Dip.	A	Teetes et al. 1980
Metagonistylum minensi tns.	Tachinidae : Dip.	A, S	Teetes et al. 1980
Theresia (Paratheresia) ciaripalpis Hulp.	Tachinidae : Dip.	C, A, S	Teetes et al. 1980
Jayneleskia jaynesi Aldr.	Tachinidae : Dip.	S	Teetes et al. 1980
Leskiopalpus diadema Wd.	Tachinidae : Dip.	A, S	Teetes et al. 1980
L. famelicus Wied.	Tachinidae : Dip.	A	Teetes et al. 1980
Parthemoleskia parkeri Tns.	Tachinidae : Dip.	S	Teetes et al. 1980
Stomatodenia flauvpennis Wied.	Tachinidae : Dip.	A	Teetes et al. 1980
Zenillia pa/pal is Aldr.	Tachinidae : Dip.	S	Teetes et al. 1980
Achaetoneura archippivora Will.	Tachinidae : Dip.	C	Lacayo 1977
Archytas sp.	Tachinidae : Dip.	C	Lacayo 1977
Eucelatoria sp.	Tachinidae : Dip.	C	Quezada 1979
Ohysarcodexia peltata Aldr.	Sarcophagidae : Dipt.	S	Teetes et al. 1980
Sarcophaga lambens Wied.	Sarcophagidae : Dipt.	A, S	Teetes et al. 1980
S. pedata Aldr.	Sarcophagidae : Dipt.	A	Teetes et al. 1980
S. rapam Walk.	Sarcophagidae : Dipt.	A	Teetes et al. 1980
S. sternodontis Tns.	Sarcophagidae : Dipt.	C	King and Saunders 1984
S. surrubea Wulp.	Sarcophagidae : Dipt.	A	Teetes et al. 1980
Apanteles xanthopus Ashm.	Braconidae : Hym.	S	Teetes et al. 1980
A. *diatraea* Mues.	Braconidae : Hum.	C, A	King and Saunders 1984
Ipobracon tucumanus Breth.	Braconidae : Hym.	S	Teetes et al. 1980
/. *grenadensis* Ashm.	Braconidae : Hym.	A, S	Teetes et al. 1980
/. *amabilis* Breth.	Braconidae : Hym.	S	Teetes et al. 1980
/. *aquaticus* Myers	Braconidae : Hym.	S	Teetes et al. 1980
/. *puberulus* Szep.	Braconidae : Hym.	S	Teetes et al. 1980
/. *saccaharalis* Turner	Braconidae : Hym.	S	Teetes et al. 1980
/. dolens Cam.	Braconidae : Hym.	S	Teetes et al. 1980
/. *puberuloides* Myers	Braconidae : Hym.	S	Teetes et al. 1980
Microbracon femoratus Ashm.	Braconidae : Hym.	S	Teetes et al. 1980
M. *chinensis* Szep.	Braconidae : Hym.	A	Teetes et al. 1980
M. femoratus Ashm.	Braconidae : Hym.	A	Teetes et al. 1980
Agathis stigmaterus Cress.	Braconidae : Hym.	A, S	Sarmiento 1981
A. (Bassus) crossi Breth.	Braconidae : Hym.	S	Teetes et al. 1980
A. (Bassus) parifasciatus Cam.	Braconidae : Hym.	S	Teetes et al. 1980
A. (Bassus) *sacchari* Myers	Braconidae : Hym.	S	Teetes et al. 1980
Iphiaulax sp.	Braconidae : Hym.	C	Cortez et al. 1980
/. rimac Wolcot	Braconidae : Hym.	S	Bartlett et al. 1978
/. *abancay*	Braconidae : Hym.	S	Bartlett et al. 1978
Eupelmus cushmani Cramani Cramf.	Eupelmidae : Hym.	S	Teetes et al. 1980
E.peruvianas Cramf.	Eupelmidae : Hym.	S	Teetes et al. 1980
Spilochalcis dux Walk	Chalcididae : Hym.	C, S	King and Saunders 1984

Continued...

Table 3. *Continued.*

Parasitoids	Family: Order	Distribution	Reference
Spilocryptus diatraea Myers	Ichneumonidae: Hym.	S	Teetes et al. 1980
Eulimneria alkae E & S.	Ichneumonidae : Hym.	A	Teetes et al. 1980
Erethmtylus flavofuscus Brull.	Ichneumonidae : Hym.	S	Teetes et al. 1980
Perisierola bogotensis kieff	Bethylidae: Hym.	S	Teetes et al. 1980
Spalangia muscidarum Rich.	Pteromalidae : Hym.	S	Teetes et al. 1980

Table 4. Distribution of predators of eggs and first-instar larvae, entomopathogens and hyperparasites of *D. saccharalis* Fab. and *D. lineolata* Walk, in Central America (C), Antilles (A), and South America (S).

Predators	Family: Order	Distribution	Reference
Cicloneda sangunea L.	Coccinellidae : Col.	C,	Mendonca 1986
Coleomegilla maculata Deg.	Coccinellidae : Col.	C, S.	Mendonca 1986
Doru lineare Esch.	Forficulidae : Dern.	A, S.	Mendonca 1986
Anisolabis annulipes Luca	Labiduridae : Derm.	A.	Teetes et al. 1980
Prolabia unidentata Palis	Labildae: Derm.	A.	Teetes et al. 1980
Ectatona quadridens F.	Formicidae : Hym.	S	Teetes et al. 1980
Monomorium fioricola Jerd	Formicidae : Hym.	A.	Teetes et al. 1980
M. Carbonarium ebenimun. Forel	Formicidae : Hym.	A.	Teetes et al. 1980
Solenopsis corticalis For.	Formicidae : Hym.	A	Teetes et al. 1980
Leptotrachelus testaceus puncticollis Bates	Carabidae : Col.	C	Teetes et al. 1980
Chrysopa spp.	Chrysopidae : Neur.	C	Mendonca 1986
Chrysoperla externa Hagen	Chrysopidae: Neur.	S	Mendonca 1986
Phlugis teres Deg.	Tettigonidae : Orth.	S	Mendonca 1986
Leucage sp	Tetragnathidae : Araneida.	S	Mendonca 1986
Tetragnatha sp.	Tetragnathidae : Araneida.	S	Mendonca 1986
Epinga c.f. Ornata Peckman	Saltidae : Araneida.	S	Mendonca 1986
Entomopathogens			
Metarhizium anisopliae (Metsch.) Sorokin	Moniliacea : Moniliales	A, S	Mendonca 1986
Cordyceps barberi Giard	Clavicipitaceae : Hypocreales	c, S	Shotman 1978, Mendonca 1986
Beauveria bassiana (Bals.) Vuill	Moniliacea : Moniliales	A, S	Mendonca 1986
Entomophtora sp.	Entomophthoraceae : Entomoph.	C	Lacayo 1977
Aspergillus flavus Link	Moniliacea : Moniliales	C	Lacayo 1977
Fusarium sp.	Tuberculariacea : Moniliales	C	Lacayo 1977
Spicaria riley	Moniliacea : Moniliales	C	Cortez et al. 1984
Granulous Virus DsGV	-	S	Mendonca 1986
Hyperparasites			
Host: *Theresia claripalpis* Wulp.			
Trichopria cubensis Fouts	Diapriidae : Proctotrupoidea.	S	Meza and Koritkrowski 1967
Aulatopria tucwnana Breth.	Diapriidae : Proctotrupoidea.	S	Meza and Koritkrowski 1967
Thysanus dipterophagus Gir.	Thysanidae: Chalcidoidea.	S	Meza and Koritkrowski 1967
Melittobia sp.	Eulophidae: Chalcidoidea.	S	Meza and Koritkrowski 1967
Conostigma sp.	Ceraphronidae : Proctotrupoidea.	C, S	Meza and Koritkrowski 1967

Apparently, the tachinids, Cuban fly *Lixophaga diatraea Towns., Theresia claripalpis* Wulp., and the Amazonian fly *Metagonistylum minensi* Towns, have been most effective in reducing *Diatraea* populations. Some Latin American countries have imported these parasitoids and developed rearing methodologies for inundative releases, extending their distribution range (Box 1952; Ayquipa 1978; Bartlett et al. 1978, pp 179-181; Shotman 1978; and Badilla and Solis 1984). Likewise, the braconid *Cotesia* (*Apanteks*) *flavipes* Cam., a native from Southeast Asia, and other parasitoids are commonly being used as biocontrols of SCB in sugarcane in Latin America (Mendonca 1986).

In E1 Salvador, Reyes et al. (1987) found that techinids, braconids, and nematodes were parasitoids of NCB on sorghum. Most of them have not been identified, but according to Sequeira (personal communication), among the braconids *Alabagrus* sp. *Iphiaulax kimballi,* and *Allorhogas* sp. have been identified. *Ectatoma* sp is thought to be an effective predator of NCB young larvae. The level of native parasitism in Central America ranges from 2-19% and the techinids, as well as *Apanteles diatraea* Mues., are the most important (Lacayo 1977, Quezada 1979, Sequeira et al. 1986, Serrano et al. 1986, and Reyes et al. 1987). In E1 Salvador and Honduras, *C. flavipes* Cam., bred on SCB, has been introduced and released to control NCB in maize/sorghum cropping systems. Establishment of the parasitoid has not been documented (Reyes et al. 1987, and Sequeira, personal communication).

Chemical Control

Chemical control is often ineffective, with its timing restricted to the period of egg hatching and the first 3 instars, before the larvae enter the stem. This period only lasts about 10 days. Where the pest is important and chemical control is economical, it is necessary to carefully monitor the crop to assess egg and young larvae infestations. When 25% of the plants are infested, insecticides in dust or granular formulations can be applied into the whorl. Reyes et al. (1983) found that general applications of granular insecticides into the sorghum whorl to control Fall Armyworm *Spodoptera frugiperda* Smith, will also control stem borers.

Conclusion

The importance of stem borers as yield-limiting factors in sorghum production has been difficult to assess. Although it is generally accepted that the August-sown crop suffers more damage than the May-sown crop, there have been no in-depth studies to evaluate the economic importance of borer infestations on sorghum yield. This condition may be attributed to the fact that stem borers on sorghum, which also occur on maize and sugarcane, are considered occasional or minor pests and research on them in relation to sorghum is limited. The way sorghum is generally used in Central and South America (animal feed and alcohol production), in contrast to use in Africa and Asia where it is a major food source in the diet of the population, may also account for this lack of information. Moreover, it appears that there are a number of sorghum genotypes with good levels of borer resistance and this, combined with the large complex of natural enemies, may explain why farmers have not recognized stem borers as pests of economic importance.

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Discussion

Wightman: Is the taxonomy of stem borers adequately known?

Harris: Authoritative taxonomic revisions of the main genera have been published: on *Diatraea:* Tarns and Bowden on *Busseola* and *Sesamia;* and Bleszynski on *Chilo* and *Acigona.* So the species are therefore recognized as good, morphologically separate taxa, although Kaufmann has suggested subspeciation of *B. fusca* in Nigeria. If there are any instances where there is good evidence to suggest the need for further taxonomic research it should be undertaken.

Seshu Reddy: The distribution of stem borers and their incidence should be thoroughly worked out. The time of attack by the stem borers in relation to crop phenology and the density of borer population at the time of attack are important factors in crop loss assessment.

Leuschner: In Andhra Pradesh, India, farmers make use of crop residues to the maximum extent. This is a good cultural practice which reduces the carryover population. Usually there is little carryover because livestock consume the residues.

Nwanze: The distribution of stem borers of sorghum and pearl millet in West Africa was found to be associated with rainfall patterns. *B. fusca was* found south of latitude 11° 30' in Burkina Faso where rainfall was over 900 mm. Above this latitude and in the north, in the driver regions of the Sahel, *B. fusca* was replaced by *A. ignefusalis.* The same pattern was also noticed in northern Nigeria.

Tabo: It has been mentioned that in southern Africa, in Zimbabwe, four important stem borers are distributed according to latitude. Would you suspect temperature, rainfall or interaction of these two to be the most likely and important factor affecting the incidence of stem borers?

Sithole: The relative distribution of these four stem borers is probably related to rainfall patterns, temperature, relative humidity, and elevation above sea level, or the interaction of some of these factors.

Srivastava: Is there any relationship between altitude and environmental conditions on the distribution of *B. fusca?*

Sithole: In southern Africa, *B. fusca* is most prevalent at higher elevations (>900 m) which are cool and receive high rainfall. The incidence of this species is lowest at lower elevations (<700 m) which are warm and receive low rainfall.

Pawar: How much damage has been generally experienced by African farmers due to stem borer damage?

Sithole: In Zimbabwe, borer infestation levels in farmers' fields varies from 15-40%, but information on real yield loss is not known.

Seshu Reddy: Some of the farmers in Kenya are aware of the extent of damage or losses caused by stem borers, but most are not. Farmers are being educated on this aspect, on the reduction of food losses through pest management strategies, and about the use of small-scale and low-cost farm equipment.

Sharma: Since deadheart formation is the most important component of yield reduction, to what extent was deadheart formation observed in farmers' fields?

Sithole: In farmers' fields deadheart formation is normally less than 20%, but varies from season-to-season.

Nwanze: Does anyone know why stem tunneling does not appear to be correlated with grain yield? Are we fully conversant with borer biology and behavior? What is happening when low borer infestations result in increased grain yield?

Leuschner: Stem tunneling on fully expanded internodes is not important. Attack on unexpanded internode below the immature head can cause damage such as poor head exsertion or chaffiness.

Vidyabhushnam: The most serious damage caused by stem borers is through peduncle boring. The shorter peduncle types are apparently prone to higher damage. Has any scientific study been conducted to establish the relationship between peduncle length and borer incidence?

Taneja: We have noticed that in West Africa even lines with long peduncles have shown considerable ear shedding.

Leuschner: In that situation, it is not peduncle length but diameter of the peduncle in relation to head size that should be considered.

Singh: Our observations and results indicate that long peduncle types suffer more damage with higher numbers of holes, larvae and pupae, tunnel length, and percent stem tunneling. Studies on inheritance of peduncle and stalk resistance also indicated that these were independent while the number of holes and degree of tunneling in stem (stalk and penduncle) are governed by nonadditive genes, the heritability was however, low.

Shinde: Not all sorghum entries which show leaf injury produce deadhearts. In such cases how does one estimate the intensity of damage? Varieties showing dcadhearts in one location do not produce deadhearts in other parts of the state. What could be the reason?

Seshu Reddy: Deadheart formation depends on the density of borer population, time of attack, and mode of larval entry in the plant. Damage intensity can be estimated from the number of plants damaged, or by scoring the damage on individual leaves and taking an average for the plant. It is a fact that deadheart formation within a region may occur in one location and not in another. Even adjascent fields may show quite distinct levels of infestation. This is due to the borer population prevalent in an area and the time of attack in relation to the phenology of the crop.

Gold: Given the limitations of cultural practices as evolved by small farmers and that they are not successful in controlling pests, it is important to consider the change in insect populations in different intercropping trials. Is there any reduction in stem borer damage as a result of intercropping?

Seshu Reddy: Under sorghum/cowpea intercropping it was observed that there is increased activity of natural enemies. The crop mixture appears to affect the visual stimuli and orientation of different insects.

Pawar: Research in India and Africa has shown that cultural practices have good pay off provided they are followed synchronously by farmers.

Nwanze: Most of the cultural practices exercised by farmers have evolved over time. The role of these various practices needs to be precisely understood in order to develop an effective IPM package for controlling stem borers.

Lavigne: What chemicals are the best for the control of *Diatraea* in central and southern America?

Reyes: Chlorpyrifos 2.5 g (13 kg ha^{-1}), phoxim 2.5g (12 kg ha^{-1}), and Trichlonfon, Metaniclofos 600 (1.4 1 ha^{-1}). Application is recommended 20-30 days after plant emergence and before booting.

Gadalla: What chemicals are used to control stem borers in southern Africa? What degree of success has been obtained in terms of field gain?

Sithole: Carbofuran, endosulfan, carbaryl, trichlorfan, and synthetic pyrethroids are used in commercial farms and sorghum grain yields of up to 5 t ha^{-1} are obtained. In resource-poor farmers' fields, the yield is generally less than 1 t ha^{-1} where chemical control of stem borers is not practiced.

Hussain Mao Haji: ICRISAT distributes international nurseries throughout the SAT. These are not attractive lines and it is impossible to use the resistant lines in our breeding programs. What purpose then is this distribution to national programs, and how can they make use of these lines?

Taneja: The purpose of sending these nurseries is twofold: first, to test the stability of resistance across environments, and second promising breeding lines are included in these nurseries, which can be directly used in the national programs if they find them useful.

Bionomics and Control
(Except Host-plant Resistance)

Bioecology of Sorghum Stem Borers

K.M. Harris[1]

Abstract

The evolution and significance of the stem boring habit in Lepidoptera is reviewed, with particular reference to the main genera with larvae that are specialized borers in the stems of Gramineae. Important elements of the biology and ecology of sorghum stem borers are summarized, including host-plant associations and geographical ranges, and the main interactions between adult and larval sorghum stem borers and their host plants are reviewed to determine their relevance in pest epidemiology and the development of effective control measures.

Résumé

***Bioécologie des foreurs des tiges du sorgho :** L'évaluation et l'importance du comportement de foreur des tiges chez les lépidoptères sont étudiées, en faisant particulièrement référence aux principaux genres dont les larves sont des mineurs inféodés aux tiges de graminées. Des données importantes de la biologie et de l'écologie des foreurs des tiges du sorgho sont résumées y compris leur association à certaines plantes hôtes et leur répartition géographique. Les principales interactions entre les foreurs (larves et adultes) et leurs plantes hôtes sont étudiées afin de déterminer leur rôle dans l'épidémiologie des ravageurs et la mise au point des mesures de lutte efficaces.*

Introduction

During the evolution of the Lepidoptera, the specialized larval habit of feeding in stems of Gramineae and Cyperaceae developed as part of the complex interaction between this major Order of insects and flowering plants. The earliest fossil insects date from the Upper Devonian, about 360 million years ago but the Lepidoptera evolved much more recently. Their earliest known fossils date from the Eocene, about 60 million years ago. With the exception of a few carnivorous groups whose larvae feed mainly as predators on scale insects and mealybugs, most lepidopterous larvae are phytophagous. The plants on which they feed are mainly angiosperms, which first appear in the fossil record in the early Cretaceous, about 135 million years ago. Phytophagous larvae may be general or specialist feeders on roots, stems, bark, branches, twigs, leaves, buds, fruits, seeds, or galls. It is generally considered that larvae of the more primitive families (e.g. Hepialidae, Cossidae) feed in concealed situations in the soil or as borers, leaf-miners, leaf-tiers or case-bearers and that larvae feeding in exposed positions on plants, such as the many leaf-feeding species, usually belong to the more advanced families of Lepidoptera (Riek 1970).

The Gramineae, as with the Lepidoptera, evolved comparatively recently, probably originating in the Mesozoic, with the earliest known fossils dating from the late Tertiary, about 25 million years ago. (Gould and Shaw 1983). Both groups have been highly successful in evolutionary terms. Gramineae are currently represented by about 7500 species, and Lepidoptera by 200000 species.

Strong interactions between Gramineae and Lepidoptera have evolved over at least the past 25 million years and, as a result, the specialized habit of stem boring in grasses has developed in the following main groups:

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Pyralidae

Crambinae *Coniesta, Chilo, Diatraea,* etc.
Pyraustinae *Ostrinia*
Galleriinae *Eldana*
Phycitinae *Elasmopalpus, Maliarpha, Emmalocera*
Schoenobiinae *Scirpophaga, Schoenobius, Rupela,* etc.

Noctuidae

Amphipyrinae *Busseola, Sesamia, Manga, Poeonoma,* etc.

Castniidae

Castnia

Against this evolutionary background, the development of stem boring on cultivated sorghum and other cereal crops is comparatively recent. The crop itself is probably not more than about 5000 years old. The main sorghum varieties cultivated today are even more recent, and probably differ substantially in physical and chemical attributes from their wild grass precursors.

Most of the information that is available on the biology and ecology of sorghum stem borers relates to crop hosts (sugarcane, maize, sorghum, rice, and pearl millet) rather than to noncrop hosts, which are mainly grasses. This information has been summarized in general reviews of sorghum pests (Young 1970, Young and Teetes 1977), and in specialized reviews on lepidopterous stem borers (Jepson 1954) and on sorghum stem borers (Harris 1985). An extensive bibliography, with informative abstracts, is available in CAB Annotated Bibliography E. 105, Stemborers of Sorghum 1973-87, issued by the CAB International Institute of Entomology (CIE). The following accounts of the major pest species highlight some of the more important elements of that information, with emphasis on recent published work and key references.

Chilo partellus (Swinhoe)

Distribution

This is the most important stem borer of sorghum in Asia and parts of Africa. It occurs throughout the Indian subcontinent and throughout Southeast Asia to Indonesia and Taiwan. It first appeared in East Africa in the early 1950s and has now spread as far as northern Sudan, Botswana, and Zaire (Ingram 1983) and may have spread westward from the Sudan to West Africa.

Host Plants

Sorghum, maize, pearl, foxtail and finger millets, wheat, sugarcane, and rice are the main cultivated hosts attacked. Wild grass hosts include *Sorghum halepense, S. verticilliflorum, Panicum maximum,* and *Pennisetum purpureum.*

Adult Biology and Ecology

Neupane et al. (1985) have published a recent account of this species in Nepal, including observations on adult activity, and have commented on previously published observations from India and East Africa. Details vary with location, due to climatic and other factors, and the following general account should be supplemented by reference to relevant local information, when necessary.

Adults emerge from pupae in stems during the late afternoon and early evening and are active at night. During the day they are inactive, resting on plants and plant debris and, because of their cryptic coloration, are seldom noticed unless disturbed. Females release pheromones to attract males and mate soon after emergence. The components of the female pheromone have been identified by Nesbitt et al. (1979) as (Z)-11-hexadecenal and (Z)-11-hexadecen-1-01 and some work on the use of pheromones to monitor this species has been done at ICRISAT (Campion and Nesbitt 1983).

On 2-3 consecutive nights, females locate suitable host plants and lay about 10 batches of 10-80 overlapping eggs on the underside of leaves, mainly near the midribs. Adults are generally shortlived (2-5 days) and do not seem to diseperse far from emergence sites, although there are records of movements of up to a few kilometers. There is no evidence of migration over substantial distances, although the spread of this species in Africa during the past 30 years may have resulted from adult dispersal flights.

Mechanisms of host location and identification have not been adequately researched, although some work has been done recently. Chadha and Roome (1980) studied oviposition behavior of *C. partellus* on maize seedlings. Oviposition started about one hour after dark and batches of 10-200 overlapping eggs were laid in a precisely ordered sequence, parallel to the long axis of the leaf. Contact with the leaf surface by antennae, ovipositor tip, and possibly the tarsi, were all involved in choice of the oviposition site. Examination of the ovipositor tip by light, scanning and transmission electron microscopy identified two pairs of chemoreceptor sensilla among many mechanoreceptor sensilla. These sensilla may prevent oviposition on surfaces that are chemically harmful to the eggs but it was noted that, in the absence of smooth plant surfaces, eggs are deposited on other smooth surfaces, even glass, polyethylene, metal or plastic indicating that the ovipositing female seems indifferent to the suitability of the surface as food for its larvae. However, Chapman and Woodhead (1985) noted that if plant leaves are present they are preferred as oviposition sites, so there must be some measure of recognition and preference. They also note that brown, dry leaves are preferred to green, turgid leaves.

Larval Biology and Ecology

Larvae emerge after about 4 8 days, hatching from early morning before sunrise to around 0800 h. The larvae then climb up young sorghum plants within the first 2-3 hours after hatching and enter the leaf whorl, where they settle to feed on young leaf tissues. The mechanisms determining this behavior and the factors affecting survival have been studied in detail in recent years (Chapman et al. 1983, Bernays et al. 1983, and Bernays et al. 1985). On hatching, larvae are positively phototaxic and move upwards from hatching sites on the lower leaves. This phototactic response is quickly lost under the influence of host odor and darkness, as larvae approach the leaf whorl. These reactions usually ensure that most larvae quickly become established in the whorl. Positive phototaxis is also modified when larvae stray from the stem onto the leaves during their upward movement. Contact with a leaf edge usually results in downward movement until a larva regains the stem; it then continues to move upwards. There are additional directional cues in leaf structure, including large veins and distally directed spines. Leaf waxes and plant odors also seem to have some effects on the behavior of first instar larvae. Since successful establishment of early instars on young plants mainly determines deadheart incidence and subsequent yield losses, these studies are very important in elucidating useful resistance mechanisms.

Chapman et al. (1983) observed larval survival and dispersal on two sorghum cultivars in India during the first six days after hatching. In a series of four experiments, 20-50% of the larvae were present in the leaf whorls within six hours of hatching. By the third day, virtually all surviving larvae were in leaf whorls, but mostly in plants other than those on which they had hatched. One day after hatching on small plants (25-40 cm tall) about half of the larvae had moved to adjacent plants. The number of larvae present in plants declined during the first three days but then stabilized.

Subsequent instars tunnel into the stem tissue of the host plant. Singh and Rana (1984) reported detailed laboratory and field studies of oviposition, larval development and pupal weights on 70 sorghum cultivars and correlated these parameters with symptoms of field damage (deadhearts, number of holes/tunnels and percent tunneling). They concluded that ovipositional nonpreference and antibiosis act together to determine the degree of resistance, but that antibiosis has the greater effect. Antibiosis was expressed in slower larval development, higher larval mortality, and lower pupal weights. Antibiosis factors operated in leaf and stem tissues. In the absence of these factors, larvae generally developed faster and produced heavier pupae when fed exclusively on leaf whorl tissues rather than on stem tissues.

After 2-4 weeks, nondiapause larvae pupate in the galleries that they have excavated in the stems. Adults emerge from pupae about 5-12 days later. When climatic conditions are favorable, the life cycle is completed in about 25-50 days. Up to five or more successive generations may develop annually. During cold and/or dry seasons, larvae enter diapause in stems and stubble for up to six months. When conditions become favorable for further development, they pupate. The factors breaking diapause do not seem to have been adequately studied.

Population Dynamics

Information on factors that determine population dynamics of *C. partellus* on sorghum crops, or in other crop ecosystems, is available in various publications but has not been fully integrated into research programs. Climate and host availability/suitability must be important, as must mate location, host location, ovipositing success, and first-instar larval survival and establishment. The many causes of mortality must also be important, including physical, chemical and biological factors, that operate on egg, larval, pupal and adult stages. Many pathogens, predators, and parasites are known but their significance in regulating *C. partellus* populations is not.

Ingram (1983) reviewed work on the biological control of this species in Pakistan and East Africa. *Apanteles flavipes (*Cameron)became an important parasitoid in Pakistan after its introduction and release from Japan (Alam et al. 1972), but similar introductions of *A. flavipes* and other parasitoids from India to East Africa failed to establish (Ingram 1983). Research on *A. flavipes* in Pakistan by Mohyuddin et al (1981) showed that strains of the parasitoid are attracted to the frass of a particular stem borer, feeding on a particular host plant.

Six other species of *Chilo* have been reported on sorghum in various parts of the world (Seshu Reddy 1985). These are of minor importance compared to C. *partellus.*

***Busseola fusca* (Fuller)**

Distribution

This is the most widespread stem borer of sorghum in Africa south of the Sahara. It has been reported in most countries from Guinea in the west to Somalia in the east, and southward to South Africa. It is a major stem borer of sorghum in Burkina Faso. but does not occur north of latitude 11° 3'N, although it occurs as far north as 12° 6' N in Nigeria (Nwanze 1985).

Host Plants

Maize, on which *B. fusca* is an important pest, sorghum, sugarcane, and, to a lesser extent, pearl millet are all host plants. Wild grasses such as *Sorghum verticilliflorum, Pennisetum purpureum, Hyparrhenia rufa,* and *Panicum maximum* are also host plants.

Adult Biology and Ecology

van Rensburg et al. (1987) have published the most recent account of the ecology of *B. fusca,* based on their work in South Africa, and refer to earlier publications on the biology and ecology of this species. Key references given in their bibliography inlcude: South Africa—Mally (1920), du Plessis and Lea (1943), van Rensburg (1980); Zimbabwe—Smithers (1960a, 1960b); Tanzania-Swaine(1957); Uganda-Ingram (1958); and Nigeria—Harris (1962, 1963), and Usua (1970, 1974). In addition, Kaufmann (1983) published a paper on food plant adaptations of different populations in Nigeria, and Adesiyun (1983) has recorded the effects of intercropping on this species, also in Nigeria.

Adults emerge from pupae in stems and stubble during the evening and are active at night, resting on plants and plant debris during the day. As with most stem borer adults, they only fly during the day if disturbed. Females release a pheromone soon after emergence to attract males, and the components have been identified as (Z)-11-tetradecenyl acetate and (E)-11-tetradecenyl acetate by Nesbitt et al. (1980) and Hall et al. (1981).

During the 3-4 nights following emergence, females lay eggs in batches of 30-100 under the vertical edges of leaf sheaths, laying a total of about 200 eggs per female, van Rensburg et al. (1987), working with maize, observed that the sheath of the youngest unfolded leaf is most attractive for oviposition and that egg laying is concentrated on plants that are less than 8 weeks old. They also recorded that the egg batches of spring moths were smaller than those of summer moths, possibly because the body reserves of spring moths are smaller.

Larval Biology and Ecology

Larvae hatch about a week later and disperse over plants before entering the leaf whorls to start feeding. Presumably their behavior is similar to that of *C. partellus* first-instar larvae, but there do not seem to have been any detailed recent studies of *B. fusca* on sorghum, van Rensberg et al. (1987), working with maize, recorded that 81% of lavae up to the fourth instar were found in leaf whorls. Fifth instars were more evenly distributed in the plants. Sixth instars were found in considerably larger numbers than the previous instars in the stems and ears. The number of fifth instar larvae reached a peak at 8 weeks after plant emergence, and only sixth instar larvae were found in stem bases, due to the commencement of diapause in later plantings. They also noted that the extent of larval migration within crops was underestimated by earlier workers, since at least 4% of the total number of larvae in a planting migrated to adjacent plants directly after hatching. The average number of larvae per infested plant changed continually due to migration during crop development.

Larval development generally takes 24-36 days before pupation in plant stems or stubble. Adults emerge about 9-14 days after pupation and the life cycle in favorable conditions is completed in about 7-8 weeks. In dry and/or cold conditions, larvae enter diapause for six months or more and diapause is broken during subsequent rains. Usua (1970) studied diapause in detail on maize in southern Nigeria and reported that diapausing larvae are present throughout the year, irrespective of the condition of the host plant, but with peak incidence in July and December. He concluded that the presence of water does not terminate diapause in the field. In a later paper on the physiology of diapause and nondiapause larvae, Usua (1974) concluded that the main factor enabling diapause larvae to survive adverse conditions appears to be their efficient water conservation mechanism. Harris (1962), reporting studies of this species in northern Nigeria, where rainfall ceases completely during the five-month dry season, observed that diapause was terminated at the end of the dry season when larvae drank water. Larvae that had been kept in dry sorghum stems in a laboratory for five months drank immediately when given access to drops of distilled water; their weight increased by 20-40% within 24 hours, indicating rapid rehydration, and they pupated within a week. A control set of larvae maintained in a humid atmosphere did not increase in weight and did not show any marked tendency to pupate, van Rensberg et al. (1987) noted that there is no clear understanding of the factors inducing diapause, although it may be under genetic control, as suggested by Usua (1970), and that it is still uncertain which factors are responsible for breaking diapause. They also noted that unpublished work suggests that free water will advance pupation by a maximum of one week. From their own observations, it appears that diapause larvae must pass a specific period under specific conditions before certain physical conditions will induce pupation.

A second species of *Busseola* of minor importance, *B. segeta* Bowden, occurs on sorghum, maize, finger millet, sugarcane, and various grasses in Uganda and Tanzania. Ingram (1958) published a brief account of its biology in Uganda.

Diatraea saccharalis (Fabricius)

Because of its importance as a pest of sugarcane, the literature on *D. saccharalis is* substantial and mainly relates to that crop. Roe et al. (1981) published a bibliography covering the period 1887-1980 that contains 1193 citations. More recent work has been abstracted in CAB Annotated Bibliography E.49, *Diatraea saccharalis* 1973-87 issued by the CAB International Institute of Entomology.

D. saccharalis is the commonest and most widespread of the many species of *Diatraea* that occur in North, Central, and South America, with a range extending from Louisiana, North Carolina, and Texas through Mexico, Central America, and the Caribbean southward to Argentina (CIE Distribution Map 5). Sugarcane is the main host plant but this species also develops on maize, sorghum and rice, as well as on Johnson grass (*Sorghum halepense*). Pampas grass (*Cortaderia selloana*) and other grasses, including *Cymbopogon citratus* and *C. nardus.*

A detailed, illustrated account of this species in the United States was published by Holloway et al. (1928) and is probably still the best overall account of its biology and ecology, with detailed descriptions of life stages and damage symptoms. There are obvious similarities with *Chilo partellus.* Oviposition starts at dusk and continues during the 3-4 nights following adult emergence. Batches of up to 50 eggs are laid on upper or lower surfaces of leaves in overlapping, generally elongated clusters. After 4-9 days larvae hatch, and, for the first week, often feed within the leaf-sheath or between the leaf-sheath and stem. They then tunnel into the stems to feed, and eventually pupate, after first preparing exit holes. The life-cycle from egg to adult is usually completed in 35-50 days when conditions are favorable. In tropical areas, continuous development may produce as many as seven generations annually. In the northern and southern parts of its range, *D. saccharalis* larvae enter diapause in the winter and carryover to the following season in crop residues.

Pheromone studies with this insect have been reviewed by Hammond and Hensley (1971) and other aspects of its biology and ecology that have been studied in recent years include: the influence of climatic factors (Mendes 1978); the height and time of adult flight in Brazil (Mendes et al. 1978); seasonal abundance in Texas (Fuchs and Harding 1979); induction and termination of larval diapause in Texas (Fuchs et al. 1979); fluctuations of adult populations in Brazil (Teran 1979); larval density and the effects of parasites and pathogens in Brazil (Teran 1983); and laboratory studies of oviposition and development in Brazil (Bortoli and Manprim 1984).

Other species of *Diatraea* that attack sorghum, mainly *D. lineolata* (Walker), *D. grandiosella* (Dyar) and *D. crambidoides* (Grote), have not been studied to the same extent as *D. saccharalis.*

Coniesta ignefusalis (Hampson)

Harris (1962) published a detailed, illustrated account of the biology of this species in Nigeria. In a review on pests of pearl millet in West Africa, Gahukar (1984), included references to two subsequent publications on this species in Senegal. *C. ignefusalis is* known to occur across the Sahel belt of West Africa from Senegal through Niger and northern Nigeria to Chad. Its preferred host plant is pearl millet but larvae also feed on sorghum, especially when it is intercropped with millet, and on maize and some wild grasses, including *Pennisetum purpureum.*

At Zaria, Nigeria, Harris (1962) observed that adults emerged from pupae in stems between 1900 and 2300h in a caged experiment. Both sexes flew within three hours of emergence and mated either on the night of emergence or early the following night. Eggs were laid between the leaf sheath and stem, in batches of 20-50, with up to 200 eggs laid per female in captivity. Larvae hatched after 12 days and at first remained clustered under the leaf sheaths, but within 24 hours they started to tunnel into the leaf sheaths and underlying stems. They did not disperse over the plant or concentrate in leaf whorls but dispersed through the plants partly by active tunneling and partly by upward movement in the leaf sheaths as they grew. Some larval migration occurred between plants but the maximum spread from known oviposition sites was 1.2 m in the insectary and 1.8 m in the field. During the wet season larvae completed development in 30-40 days, pupation lasted 7-13 days, and three generations developed with an average life-cycle of about 57 days. Toward the end of the wet season, larvae entered diapause and carried over in dry stems and stubble until the end of the 5-6 month dry season.

The North American species, *Eoreuma loftini* (Dyar), is related to *C. ignefusaJis* but is mainly a pest of sugarcane. It seems to be of relatively low importance as a stem borer of sorghum.

Eldana saccharalis (Fabricius)

Ingram (1983) records that this African species is primarily a borer of *Cyperus* species and probably attacks crops opportunistically when they have replaced its natural hosts. It is principally a pest on sugarcane and details of its life history, development, and behavior on that host plant in Ghana have been published recently by Sampson and Kumar (1985). In Ghana, mated females laid about 300-350 eggs over a four-day period, in batches, mainly under leaf sheaths. Eggs hatched after 5-7 days and early instar larvae dispersed during the first three days before settling to tunnel into stems. Larval development lasted about 31 days, followed by pupation in bored stems for 7-13 days, and the life-cycle was completed in 36-62 days. Girling (1978) reported observations on the distribution and biology of this species in Uganda and also assessed its crop pest status in Ghana (Girling 1980). Atkinson (1980) reported its biology, distribution, and natural host plants in South Africa. Nwanze (1985) recorded that this is the predominant borer on sorghum during August and September in Burkina Faso but it appears to be restricted below latitude 12°N in both Burkina Faso and Nigeria.

Sesamia Species

At least eight species of *Sesamia* have been recorded as stem borers of sorghum, mostly in Africa but also in Europe, Asia and the Pacific. Their geographical ranges have been summarized by Harris (1985) and Seshu Reddy (1985). *S. calamistis* Hampson is probably of greatest overall importance in Africa south of the Sahara, where *S. botanephaga* Tarns and Bowden, *S. nonagrioides* (Lefebvre), *S. poephaga* Tarns and Bowden, *S. penniseti* Tarns and Bowden and 5. *albivena* Hampson also occur. *S. cretica* Lederer is present in Ethiopia, Somalia, Sudan and the western Mediterranean and *S. inferens* (Walker) occurs in the Indian subcontinent. Southeast Asia, and as far east as the Solomon Islands.

Host ranges of these species are generally similar, including maize, sorghum, pearl millet and other millets, and various grasses. Accounts of the biology of the species vary in the amount of detail available but information on *S. calamistis*is probably typical. In Uganda, Ingram (1958) recorded that batches of up to 20 eggs were laid under leaf sheaths, as in the case of *B. fusca,* with females laying about 300 eggs each, over 2-3 nights. Eggs hatched 7-9 days later and first-instar larvae bored straight into the stems, with only occasional feeding in the leaf whorl, in marked contrast to the behavior of first-instar

B. fusca larvae. Some larvae migrated to other plants during development, which took 27-36 days in the laboratory. The life-cycle in the laboratory was completed in 45-58 days and breeding continued throughout the year, without any larval diapause. Harris (1962) recorded similar details of the biology of this species in Nigeria and confirmed that, despite the severe dry season, there was no larval diapause and the species continued to develop throughout the year.

Ingram (1958) recorded that the larvae of *S. poephaga* enter the stem through the leaf whorl, so differing from *S. calamistis,* but Harris (1962) reported that in Nigeria they bored directly into the stems under the leaf sheaths. There is obviously scope for further study as this is an important difference in behavior that must affect mortality factors and control. There seems to have been little recent research on either *S. calamistis* or *S. poephaga* but a few post-1972 papers refer to *S. inferens* and *S. nonagrioides.*

Other Sorghum Stem Borers

Elasmopalpus lignosellus (Zeller) is a minor pest of sorghum in North, Central, and South America; *Ostrinia furnacalis* Guenee has been recorded from sorghum in Japan and *Ostrinia nubilalis* Hubner, the European corn borer, occasionally attacks sorghum in North America. None of these species seems sufficiently important to merit in lusion in detail in this review.

Conclusions

From the above accounts of the main species of sorghum stem borer, it is clear that much information is available on their biology and ecology, but it has been obtained mainly by individual research workers operating in piecemeal fashion over the past 50 years. There has been no clearly integrated approach toward an understanding of the ecology and epidemiology of the main species that would assist the development of effective pest management. One possible exception is the work on *Diatraea saccharalis* in the USA and South America, but that relates to sugarcane, not sorghum.

Jepson (1954), concluding his review of the world literature on lepidopterous stem borers of tropical graminaceous crops, suggested "the creation of a small international sub-committee of workers from all continents as a first step to determining the extent of the problems and in formulating proposals for the prompt exchange of scientific and technical information and for coordinating some of the principal lines of work". This Workshop may represent the first step in that direction, for sorghum stem borers, more than 30 years later.

Some research workers may accept a pragmatic approach, and maintain that rigorous and extensive selection and breeding for host-plant resistance will eventually provide acceptable practical solutions to stem borer problems. I accept that host-plant resistance does offer the most feasible long-term solutions for much of the tropics but am convinced that a better entomological understanding of the biology and ecology of the pest species will result in improved resistance and better overall pest management. That will require more and better-organized information on key aspects: the extent of adult dispersal/migration; mate location; courtship behavior; host location and selection; oviposition site selection; larval behavior; mortality factors; and population dynamics. As Young and Teetes (1977) emphasized, unique pest management systems are required for each distinct agroecosystem. Generalization is useful up to a point, but there is no substitute for accurate and detailed information.

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Chemical Control of Stem Borers

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Abstract

Chemical control is the most powerful tool available for controlling stem borers and is an important component in their management. The most important borer species on sorghum and maize are Chilo partellus, Busseola fusca, Sesamia *spp,* Eldana saccharina, *and* Diatraea *spp.*

The knowledge of specific habits and periods of peak activity of the most vulnerable stages of stem borers with appropriate formulation, method, rate, time, and schedule of application of insecticides determine the degree of success of chemical control. This paper reviews recent research and recommendations on chemical control of major stem borers, and also discusses judicious use of endosulfan and its integration with host-plant resistance.

Résumé

***Lutte chimique contre les foreurs des tiges :** La lutte chimique est l'outil le plus puissant pour l'éradication des foreurs des tiges et une importante composante de la lutte intégrée. Les principales espèces nuisibles au mais et au sorgho sont* **Chilo partellus, Busseola fusca, Sesamia** *spp.,* **Eldana saccharina** *et* **Diatraea** *spp.*

Le succès de la lutte chimique dépend de la connaissance du comportement spécifique et des périodes de pullulation des stades les plus vulnérables des foreurs ainsi que des formulations et concentrations des insecticides et de la méthode, dates et calendrier des applications. De récents travaux et des recommandations sur la lutte chimique contre les principaux ravageurs sont rappelés, en particulier l'utilisation judicieuse de l'endosulfan et son association avec l'exploitation de la résistance variétale.

Introduction

Chemical control, despite its limitations, is an important tool for consideration in any integrated pest management program, especially in treating epidemics. It requires application methods based on specific insect habits, peak period of activity, and vulnerable stages of the life cycle. Economic thresholds are also important considerations of chemical control, both for effective application and for minimum impact on environment (avoiding destruction of natural enemies of pests by toxic residues).

Most work on chemical control of stem borers in India has been done on *C. partellus,* while very little has been done in East Africa (Coaker 1956, Nye 1960, and Kayumbo 1976). Chemical control of stem borers in South Africa has been reported tobe ineffective (van Rensburg and van Hamburg 1975). Besides *C. partellus,* attention has been given to use of insecticides for the control of rice stem borers, *B. fusca* and *Maruca testulalis.* Little information is available on the chemical control of other cereal stem borers.

Soil Furrow Application at Sowing

Chemical control of *C. partellus* through soil furrow application at sowing of systemic insecticides such as cytrolane 5G, carbofuran 5-10G, aldicarb 10G,

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mephosfolan 10G, phorate 10G, and disulfoton 10G, at 0.7-2.0 kg a.i. ha^{-1} has been tried with success (Grewal 1969, Baskaran 1971, Noor and Pareek 1978, and Chatterji et al. 1972). Sharma et al.(1973) reported no differences between application of virlane, cytrolane, phorate, or carbofuran and control. Walters and Drinkwater (1975) reported significant reduction of *B. fusca* by carbofuran granules at 1 kg a.i. ha^{-1}). Similar findings were made by van Rensburg et al.(1978).

Seed Treatment

Lal et al. (1961) tried finely ground BHC and lindane as seed treatment for *C. partellus* control on maize. Gum arabic paste was used as a sticker. BHC (5g/ 100g) and lindane (20g/ 100g) of seeds gave protection against *C. partellus.* Higher concentrations were phytotoxic. Sharma et al. (1973) also tried seed treatment with carbofuran at 5.75-10 g a.i./100 g seed with little success.

Side-dressing After Crop Emergence

Jotwani (1969) determined the feasibility of controlling sorghum stem borers by side-dressing with mephosfolan and carbofuran, 20 days after emergence (DAE). Other efforts found that mephosfolan, aldicarb, and carbofuran granules applied 15-34 DAE at 1.0-2.5 kg a.i. ha^{-1} gave effective protection against *C. partellus* on maize and sorghum (Grewal 1969, Chatterji et al. 1972, and Sharma et al. 1973).

Foliar Sprays and Dusts

Foliar sprays and dusts of DDT, BHC, and parathion were used on local varieties of sorghum and maize to control stem borers (Trehan and Butani 1949, Puttarudriah 1958). Later insecticides such as endrin, carbaryl, monocrotophos, diazinon, fenitrothion, and phenthoate were evaluated for use against *C. partellus* in India (Young 1962, and Ahmed and Young 1969). Spray applications of the pyrethroids decamethrin, fenvalerate, cyloxylate, cypermethrin, and permethrin at 25-150 g a.i. ha^{-1}, were not very effective against this pest (AICSIP 1982-83).

Endrin spray at weekly intervals was effective against *D. crambidoides* (Brett 1953, and George and Wilson 1957). Two applications of carbaryl and cytrolane, either spray or dust, reduced the damage of *S. calamistis, B. fusca, E. saccharina, S. cretica, Ostrinia nubilalis,* and *C. agamemnon* on maize in Nigeria (Adeymi et al. 1966, and Saad et al. 1971). Chlorpyrifos and chlordimiform as ultra low volume sprays (ULV), and diazinon, chlorpyrifos, mephosfolan and EPN as conventional sprays, were effective against 5. *cretica* in Baghdad (Saad 1977). Spray application of chlorfenvinphos, diazinon, and azinophos methyl at 0.2-0.6 kg a.i. ha^{-1} were effective in rice against *Chilo* spp., *M. separatella, Tryporyza* spp., and *Sesamia spp.* Application of malathion 50 EC at 1.5 kg a.i. ha^{-1}, or Basudin 60 EC at 1.2 kg a.i. ha^{-1} were found effective in controlling *B. fusca, Sesamia* spp., *Chilo* spp., and M. *separatella* (Sagma 1983). A chlorpyrifos seedling root dip treatment, followed by foliar spray applications of 0.5 kg a.i. ha^{-1} at 25 and 60 DAE, effectively controlled the *Scirpophaga incertulas.* Application of mephosfolan to the root zone at 0.5 kg a.i. ha^{-1}, plus spray application four days after treatment, also effectively controlled the pest (Sasmal et al. 1984). Foliar spray of fenobucarb, cartab, and fenvalerate reduced the incidence of stem borer *Scirpophaga innotata* to a greater extent than the other insecticides (Uthamasamy and Jayraj 1985).

Leaf Whorl Placement of Insecticides

Placement of insecticide directly into the whorl of maize and sorghum plants solves the problem of keeping the chemical on the leaves at lower application rates per unit area.

Application of Granules

In early trials, endrin granules in leaf whorls gave effective control of *C. partellus* (Thobbi et al. 1968, Kulshrestha et al. 1968, and Ahmed and Young 1969). Also reported to be effective against this pest were endosulfan, carbaryl, phenthoate, quinalphos, malathion, lindane, mephosfolan, and diazinon granules at 0.600-1.200 kg a.i. ha^{-1} (Jotwani and Young 1972, Jotwani and Kishore 1973, Noor and Pareek 1978, Taley and Thakare 1979, Sandhu and Chahal 1980, and Kundu and Kishore 1980).

Helicopter application of monocrotophos 2G and endrin 3G at 20 kg ha^{-1} reduced larval population of *Sesamia* spp. on maize in Spain (Caballero et al. 1972). Single applications of carbofuran, diazinon, or chlorfenvinphos granules were also found to be effective against *S. cretica* in maize (Al-Dabbas and Al-Salih 1978).

Recommendations for the control of rice stem borers, Chilospp, *Sesamia* spp., *M. separatella,* and *T. incertuJus* include granular application of BHC, carbofuran, chlordimeform, chlorfeminphos, diazinon, fensulfothion, mephosfolam, or salithion at 0.45-2 kg a.i. ha^{-1} (COPR 1976, pp. 122-123).

Application of Dusts

Kishore and Jotwani (1977) found leaf whorl placement of dusts of endosulfan, phenothoate, carbaryl, malathion, and BHC to be economically feasible in controlling stem borers in sorghum. These findings were subsequently proved effective at different locations (AICSIP 1977-79). Results of trials conducted in 1986-87 at IARI, Delhi, showed that dust of fenvalerate applied in leaf whorls is also effective against this pest.

Swaine (1957) controlled *B. fusca* with 2.5% DDT dust applied at weekly intervals on maize. Walker (1960) reported effectiveness of endrin dust in controlling *B. fusca* on maize, van Rensburg and Hamburg (1975) could not get effective control of *C. partellus* in South Africa.

Application of Sprays

Barry and Andrews (1971) obtained satisfactory control of *B. fusca* in sorghum by applying a 1 mL spray of carbaryl mettable powder (WP) in the leaf whorls of each plant using a specially designed pistol grip sprayer.

Comparison of Application Methods

Different application methods using endosulfan, phenthoate, and carbaryl against *C. partellus,* in sorghum showed that granules and dusts were superior to sprays in realizing grain and fodder yields. Not much difference was observed between granules and dusts (Table 1, Kishore 1980). Jotwani and Young (1972) demonstrated the superiority of granules over sprays. Endosulfan spray and granules together have been found effective against this pest in maize (Mathur 1983).

Economic Threshold

Repeated applications of BHC, DDT, parathion and endrin have been tested for their ability to control sorghum stem borers. No significant difference was found between 3 and 6 applications of endrin (Thobbi et al. 1968). Various insecticide application schedules have also been tested. (Ingram 1958, Jotwani and Young 1972, Manoharan and Balasubramanian 1982, and Sachan and Rathore 1983). However, in the absence of economic thresholds for various stem borers it is doubtful that insecticide application is justified by infestation levels.

Table 1. Efficacy of different formulations of promising insecticides for the control of stem borer.

Insecticide	Borer damage: Mean leaf injury (%)	Borer damage: Mean stem tunneling *(%)*	Yield t ha^{-1} (mean): Grain	Yield t ha^{-1} (mean): Fodder	Increase in grain yield over control *(%)*	Avoidable loss (grain) (%)
Endosulfan granules	18.90	17.35	0.57	2.66	83.98	0.00
Endosulfan dust	19.16	16.21	0.57	2.40	83.85	0.10
Endosulfan spray	32.51	41.44	0.37	2.15	19.43	35.08
Phenthoate granules	19.78	17.94	0.56	2.52	81.14	1.54
Phenthoate dust	20.23	18.40	0.56	2.27	80.27	2.01
Phenthoate spray	31.63	40.58	0.36	2.09	15.94	36.98
Carbaryl granules	20.09	18.63	0.56	2.48	80.60	1.84
Carbaryl dust	20.33	19.45	0.55	2.26	78.34	4.82
Carbaryl spray	32.07	41.09	0.36	2.17	16.59	36.63
Control (No treatment)	48.30	43.97	0.31	1.76	0.00	47.40
SE	±0.026	±0.0045	±0.0085	±0.15		
CD at 5%	0.076	0.031	0.025	0.43		

Source: Kishore 1980.

Based on economic threshold studies in maize, the most vulnerable period of borer damage was found to be 10-17 DAE and the insecticide application should be initiated between 10 and 12 DAE (Sarup et al. 1977).

Kishore (1984b), working on timing and schedule of insecticide application in sorghum, found that two applications of endosulfan 4% dust at 5.0 and 7.5 kg ha^{-1}, given on 25 and 35 DAE were as effective as. and more economical than, applications given on 20. 30,40 DAE in controlling stem borer. With this schedule, the rate of application of endosulfan was reduced to 12.5 kg ha^{-1} from 22.5 kg ha^{-1} (Table 2).

Persistence and Residues

Not much work has been done on the persistence and residues of insecticides tried against different stem borers. Concern over endrin residues in sorghum contributed to the ban of its use. Studies conducted on persistence and residues of carbofuran, chlorfenvinphos, chlorpyrifos, lindane, endosulfan, fensulfothin, quinalphos, monocrotophos and tetrachlorvinphos indicate that, in most cases, significant reduction in residues was observed 45 days after application. At harvest, none of the insecticides showed detectable residues in grain, except carbofuran. The residues of carbofuran were below the tolerance limit (Srivastava 1975, Manoharan and Balasubramanian 1982, and Gururaj 1986).

Chemical Control and Integrated Control

Quantities of insecticides can be reduced to an economic level by integrating their use with resistant varieties and cultural practices (Kishore and Jotwani 1982). Studies show that endosulfan application can be integrated with 12 stem-borer resistant varieties to achieve marginal benefits under moderate levels of infestation (Table 3) (Kishore and Govil 1982, and Kishore 1984a).

Discussion and Conclusions

Stem borers of maize and sorghum can be effectively controlled by leaf whorl placement of granular or dust applications of endosulfan, phenthoate, quinalphos, carbaryl, malathion, and fenvalerate. This application targets the vulnerable stage of the pests as the larvae move towards leaf whorls after hatching. The insecticide is less affected by rain and its quantity can be reduced through this application method. Hazards of pollution residues and effects on non-target organisms can also be avoided.

Determining economic thresholds for different stem borers is desirable both to realize maximum benefit of chemical controls and to reduce the number of applications. Efforts should be made to avoid highly toxic and persistent insecticides and to

Table 2. Efficacy of different insecticidal schedules in the control of stem borer of sorghum.

Endosulfan 4% dust applied (days after germination)	Mean grain yield (t ha^{-1}) Year I	Year II	Increase in grain yield over control (t ha^{-1}) (Mean 2 years)	Cost-benefit ratio
20 at the rate 5 kg ha^{-1}	0.41	0.41	0.13	1:34.14
25 at the rate 5 kg ha^{-1}	0.42	0.43	0.14	1:37.45
20 and 30 at the rate of 5 and 7.5 kg ha^{-1}	0.41	0.42	0.13	1:14.39
30 at the rate of 7.5 kg ha^{-1}	0.35	0.36	0.07	1:13.76
35 at the rate of 7.5 kg ha^{-1}	0.35	0.34	0.06	1:11.27
20, 30, and 40 at the rate of 5, 7.5, and 10 kg ha^{-1}	0.45	0.46	0.18	1:10.87
25 and 35 at the rate of 5 and 7.5 kg ha^{-1}	0.47	0.49	0.20	1:22.25
40 at the rate of 10 kg ha^{-1}	0.32	0.34	0.04	1: 6.06
Control (No treatment)	0.28	0.29	-	-
SE	±0.021	±0.01		
CD at 5%	0.063	0.04		

Source : Kishore 1984b.

Table 3. Stem borer damage and grain yield of selected resistant varieties of sorghum with and without the application of insecticide.

	Stem tunneling by the stem borer (%)				Grain yield (t ha^{-1})				Increase in grain yield (%)	
	Year I		Year II		Year I		Year II			
Entry	Nonpro-tected	Pro-tected	Nonpro-tected	Pro-tected	Nonpro-tected	Pro-tected	Nonpro-tected	Pro-tected	Year I	Year II
E 601	11.85	9.32	14.10	12.51	0.46	0.48	0.47	0.50	6.88	4.62
E 602	13.20	10.62	15.35	13.44	0.44	0.46	0.47	0.49	7.19	4.54
E 603	13.92	11.19	15.70	14.26	0.43	0.46	0.46	0.48	6.46	3.13
E604	16.47	13.71	16.74	15.13	0.42	0.44	0.45	0.46	5.64	2.15
E 605	19.53	16.55	17.48	16.28	0.41	0.44	0.44	0.45	6.60	2.64
E 606	17.46	16.51	16.39	13.05	0.41	0.43	0.44	0.45	3.61	2.97
E 607	19.48	13.38	17.48	13.93	0.41	0.42	0.45	0.46	3.30	2.09
E 608	21.97	19.76	18.73	14.88	0.40	0.42	0.43	0.45	4.50	3.07
E 609	23.02	15.98	22.11	20.31	0.40	0.43	0.43	0.44	8.09	2.67
E 610	22.12	19.33	22.22	21.15	0.40	0.42	0.39	0.43	5.06	8.99
E611	23.63	19.75	20.31	18.23	0.38	0.42	0.40	0.42	9.14	4.79
E 612	23.58	21.41	20.46	17.95	0.39	0.42	0.39	0.43	7.05	10.67
CSH 1	45.40	29.47	41.55	28.43	0.27	0.40	0.29	0.41	48.33	40.72
Mean	20.89	16.69	19.89	16.87	0.43	0.40	0.42	0.45		
SE	±0.012		±0.0072		±0.01		±0.022			
CD at 5%	0.035		0.020		0.03		0.065			

Source : Kishore 1984a.

generate data on residues. Integration of chemicals with other methods of control is possible.

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Cultural Control of Sorghum Stem Borers

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Abstract

The role of cultural practices such as time of sowing, crop rotation, tillage, plant spacing, water management, fertilizer management, removal of deadhearts, field sanitation, removal of alternate host plants, mulching, and intercropping in the management of sorghum stem borers has been reviewed. Since the adoption of several cultural practices is either simultaneous or in close succession, it is rather difficult to ascertain the relative contribution of each practice in managing sorghum stem borers. Some commonly adopted and prevalent field and postharvest operations have been reported to contribute towards reducing the carry-over and population buildup of these pests. Since these practices do not involve much expenditure and are effective, there is a need to extend their application to farmers.

Résumé

Lutte culturale contre les foreurs des tiges du sorgho : Le rôle des pratiques culturales dans la lutte contre les foreurs des tiges du sorgho est étudié. Il s'agit de pratiques telles que le choix de la date de semis, la rotation des cultures, le labour, l'écartement des plantes, la gestion de l'eau, la fertilisation, l'enlèvement des coeurs morts, le nettoyage des champs, la suppression des plantes hôtes secondaires, le paillage et l'association de cultures. Plusieurs techniques étant appliquées simultanément ou à peu d'intervalle, il est difficile de préciser leur effet individuel dans la lutte contre les foreurs des tiges du sorgho. Certaines opérations couramment effectuées au champ et après la récolte permettent de réduire des peuplements résiduels et des pullulations de ces insectes. Celles-ci n'impliquent pas de dépenses très importantes et leur application devrait être vulgarisée auprès des paysans.

Introduction

Insect pests are one of the major yield-reducing factors in sorghum on a global basis. Nearly 150 species have been reported to damage sorghum, both in the field and in storage (Seshu Reddy and Davies 1979, FAO 1980). A wide range of lepidopterous stem borers are especially damaging to sorghum and constitute a major constraint in its production. This complex consists of 27 species spread in 10 genera of Pyralidae and Noctuidae families (Seshu Reddy 1985). Of these, *Chilo partellus, Elasmopalpus lignosellus*(Pyralidae), *Sesamia inferens,* and *Busseola fusca* (Noctuidae) are considered important worldwide.

In an effort to control these insects, crop management practices are particularly important. Cultural control of insect pests has been appropriately defined as the tactical use of regular farm practices to delay or reduce insect pest attack (Seshu Reddy 1985). This involves the manipulation of the environment to make it less favorable for insect pests and

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more favorable for crop growth. Cultural practices which directly or indirectly help to reduce pest damage have become integral components of integrated pest management (IPM) because they involve no additional expenditure and do not disturb natural enemies of the pests. Effects of various crop management practices on incidence of stem borers in sorghum has been reviewed by many researchers, including Lawani (1982), Seshu Reddy (1985), and Sharma(l985).

Cultural Practices and Related Research

Time of Sowing

One effective insect control method is sowing the crop so that its most susceptible growth stage coincides with a time when the pest is least abundant. This practice has been successful in controlling many insect pests (USA: National Academy of Sciences 1969). The importance of this practice has been repeatedly documented by research. In India, a greater incidence of *C. partellus* in sorghum sown in July than in September or October was observed. In Delhi, other studies have observed *C. partellus* to cause extensive damage to sorghum sown in June compared with that sown in July or August (Panwar and Sarup 1979). Taneja and Leuschner (1985) studied population dynamics of *C. partellus* on sorghum at Hisar by monitoring light trap catches and larval incidence on sorghum planted at monthly intervals. The highest pest incidence was observed in the crop sown during July. Singh and Verma (1983) also recorded seasonal incidence of *C. partellus* on sorghum. The pest appeared throughout the crop season from April to August with a peak infestation in the crop sown in July. At Coimbatore, Mahadevan and Chelliah (1986b) recorded the highest incidence in terms of deadheart formation, leaf injury, and stem tunneling by *C. partellus* in sorghum sown in February and March. The least damage was recorded for the crop sown in June and October.

A high correlation between time of planting and infestation has been reported by Swaine (1957), in crops attacked by *B. fusca,* a serious pest of sorghum and maize in Tanzania. Crops planted early, at the onset of the rainy season, were heavily attacked by the first generation larvae while later plantings largely escaped the damage of this pest.

It would appear that time of sowing and incidence of insects are important relative factors. While the dates themselves may be region-specific, time of sowing remains a universal cultural factor. In sorghum specifically, adjustment of planting dates can be an effective method for checking the incidence of stem borers.

Crop Rotation

Crop rotation with non-host crops reduces pest infestation by interrupting the continuity of the food chain of oligophagous pests. The importance of this practice has been supported through various research. For example, sorghum rotation with non-host crops, such as groundnut, is common practice in the Gambia. Research has shown this practice reduces the populations of stem borers (*Sesamia nonagrioides botenephaga* and *B. fusca*) in sorghum (Sagnia 1983).

Chiang and Hudson (1972) reviewed population data on *Ostrinia nubilalis* generated during 23 continuous years of monitoring. They concluded that crop rotation was the major factor that suppressed this borer population in Minnesota, USA.

Other research, on the effects of lack of rotation, is similarly conclusive. For reducing the incidence of Diatraea complex in maize and sorghum, rotation with non-host crop has in fact, been recommended in Texas (TAMU 1979).

Mohyuddin and Greathead (1970) observed that ratooned sorghum can be a significant carryover source of stem borers, for future infestation.

Tillage

Plowing after harvest is a cultural practice known to destroy stubble, weeds, and other alternate hosts of stem borers. By reducing the available host material this practice reduces the potential for carryover.

Working on sorghum in India, Gahukar and Jotwani (1980) observed a reduction in population of *C. Partellus* and also its carryover to the next crop as a result of off-season tillage. It was suggested that this practice exposed the borers to their natural enemies and to adverse climatic factors such as high temperature and low humidity.

In an early experiment, Du Plessis and Lea (1943) simulated the possible effects of plowing on *B. fusca* carryover. They buried stems containing larvae at depths similar to those which would be achieved by plowing under crop residues. They observed that moths were able to emerge from depths of up to 10 cm, but that considerable mortality occurred.

Recent research in Nigeria (Kaufmann In press), reported up to five times greater population densities of *E. saccharina, Sesamia, Calamistis, B. fusca* and *Mythimna unipunctata* in zero-tillage maize plots, compared to conventional tillage plots. In these trials, it was observed that mature borer larvae often pupated in the soil at depths of less than 10 cm during the dry season and that these larvae were possibly destroyed by tillage. Similar observations were made in maize by All et al. (1979). Infestations of the lesser corn stalk borer were greatly reduced in no-tillage compared to conventional tillage plots. The incidence of corn stalk borer, *Diatraea Jineolata* appears to increase with minimum tillage (USA: National Academy of Sciences 1975). Similarly, Musick and Petty (1973) working in the USA observed that, in general, no-tillage tended to increase incidence of *B. fusca* and *O. nubilalis in* maize crop.

In contrast to what has been reported by most other workers, All and Gallaher (1977) found that infestations of lesser corn stalk borer were greatly reduced in no-tillage compared to conventional tillage cropping systems. Increased soil moisture was found to be an important factor prohibiting infestation of this pest, and, that these conditions were enhanced in the no-tillage system. In another study, Cheshire and Griffin (1985) indicated that predators of lesser corn stalk borer were much more abundant in no-tillage than in conventional systems.

Plant Spacing

Singh (1986), found a positive correlation between the incidence of *C. partellus* and plant population per unit area in sorghum. Likewise, Chiang and Hudson (1972) observed that with an increase in the density of maize plants there was higher incidence of *O. nubilalis.* These observations suggest that higher plant density probably helps in the dispersion of larval populations. Zepp and Keaster (1977) reported a positive relationship between maize plant density and damage incidence, caused by larvae of *Diatraea grandiosella.*

Water Management

Soil moisture may influence crop damage by insect pests through its effect on plant vigor and growth. It has been shown that sorghum grown under drought stress suffers greater damage from *C. partellus* (Sharma 1985).

Effects of soil moisture content and irrigation on infestations of the lesser corn stalk borer, *Elasmopalpus lignosellus have* been extensively investigated in sorghum. (Reynolds et al. 1959, All and Gallaher 1977, and All et al. 1979). These studies showed that increased or constant soil moisture, obtained through well-timed and regulated irrigation, deterred infestations of this borer. Use of irrigation has been suggested as a method to control this pest. In rainfed agriculture, however, there is little scope for manipulating soil moisture except through moisture conservation.

Fertilizer Management

Fertilizer application is known to influence the susceptibility of crops to insects. Fertilizers enhance plant nutrition which can influence the longevity and fecundity of insects, and the degree of damage they cause (USA: National Academy of Sciences 1969).

Infestations in maize of *C. partellus* (Singh et al. 1968, and Singh and Singh 1969), and *C. partellus* and *S. interens* (Singh and Shekhawat 1964) have been shown to increase with enhanced levels of nitrogen applied to the crop. Similar findings are reported for *C. partellus* infestations in grain sorghum (Starks et al. 1971). In studies conducted by Singh and Shekhawat (1964) the borer incidence in maize was not affected by different phosphate treatments. Starks et al. (1971) working on sorghum, however, observed more *C. partellus* incidence when both nitrogen and phosphorous fertilizers were used. Kalode and Pant (1967) found that maize varieties susceptible to *C. partellus* had higher nitrogen content than resistant varieties.

Removal of Deadhearts

Removal and destruction of deadhearts in sorghum, if carried out by farmers over large areas, has been found to be a successful practice in reducing infestation of *C. partellus* (Seshu Reddy 1985). Destruction of central shoots showing early pinhole damage (these contain a large number of young stem borer larvae, ready for dispersal to adjacent plants) has also been found to be an effective practice (Kishore and Jotwani 1982).

Management of Crop Remnants

Jotwani and Srivastava (1982) reported the overwintering of stem borer larvae in stubbie left in the field or in the harvested stems stored for fodder. Studies on carryover of *C. partellus* in different parts of sorghum and maize plants during off-season have been conducted by several workers (Rehman 1944, Singh et al. 1975, Taley and Thakare 1978, and Kishore and Jotwani 1982). Almost all of them observed that carryover of the pest occurred in left-over stubble and stalks.

Field Sanitation

This pratice involves the removal or destruction of crop residues, weeds, and nearby wild host plants to eliminate a pest by destroying its food and shelter. As with tillage, this practice is intended to reduce the ability of insects to carryover to the next season. According to Aikins (1957), economically important stem borers on sorghum in Ghana, *Sesamia* sp, *Eldana* sp. and *Busseola* sp., survive the dry spell by finding fresh cereal or grass growth suitable for oviposition and on which the newly hatched larvae can subsequently feed. He suggested that grasses, stubble, and pieces of sorghum stems left after harvest be destroyed because this material provides a medium to sustain populations of these pests.

In Tanzania, Duerden (1953) achieved nearly complete eradication of *C. partellus* and *B. fusca* on sorghum and maize following burning of stubble and crop residues. Ingram (1958) and Nye (1960) recorded considerable reductions *C. partellus* and *B. fusca* populations at the beginning of the sorghum-growing season, following destruction of all crop residues and wild species of sorghum around cultivated areas in East Africa.

Most stem borers have wild plant hosts in addition to their cultivated hosts (Jepson 1954). Seshu Reddy and Davies (1980) reported five cultivated and ten wild plants as hosts of *C. partellus* in India. Working in Botswana, Roome (1976) observed Sudan grass to be heavily infested with *C. partellus. Sesamia* sp also has many graminaceous hosts including elephant grass, buffalo grass, and finger millet (Ingram 1958).

Research has brought recognition to the importance of field sanitation as a cultural practice to reduce stem borer infestations. Destruction of crop residues and other potential host carryover material has been widely recommended.

Adesiyun and Ajayi (1980) studied the effect of different practices of dealing with sorghum stalks after harvest on survival of *B. fusca* larvae. The authors observed that recommended practices of burning stalks or spreading them in the field, were not followed by farmers. They further observed that more than 95% of the farmers kept their stalks in stacks, sometimes in the shade. This allowed the survival of the diapausing larvae inside the stalks. Partial burning of the stalks immediately after grain harvest (to cure them for use as fuel) was found to kill 95% of the larvae with no damage to the stalks. This practice has been recommended as a compromise to complete burning and allows farmers to utilize the stalks for building, fencing, and fuel.

Mulching

In Uganda, nontreated crop residues are often used to mulch the next sorghum crop. Subsequent levels of stem borer infestation have been found to be far higher than normal for the area (Mohyuddin and Greathead 1970). Research by Gill (1963) observed that mulching increased the incidence of stem borer *Chilo infescatellus* in the ratoon crop of sugarcane. In maize, research has shown that mulches of wheat and rye residue provide feed to lesser corn stalk larvae, which diverts them from attacking the maize crop (Cheshire and All 1979).

Intercropping

The principle of controlling insect pest populations by increasing the diversity of an agroecosystem has been discussed by many authors, including, Smith (1972) and Solomon (1973). Intercropping has some potential as a cultural method to control stem borer infestation of sorghum.

Growing sorghum in association with other crops has been shown to reduce *C. partellus* damage on sorghum, mungbean, urd bean, pigeonpea (Singh and Singh 1974); cowpea (Omolo and Seshu Reddy 1985, and Mahadevan and Chilliah 1986a); lablab bean (Mahadevan and Chelliah 1986a, and Sadakathulla and Mani 1978). Chand and Sharma (1977) also found that growing maize in association with legumes reduced *C. partellus* damage on maize. Research has shown that intercropping of maize and sorghum without association with a cereal crop gives rise to higher incidence of *C. partellus* (Singh and Singh 1974). Other research by Amoaka-Atta et al.

(1983) reported that the incidence of *C. partellus, B. fusca, E. saccharins* and *S. calamistis* in trials of sorghum and maize monocrops, and maize/sorghum dicrops, was earlier than in trials intercropping these cereals with cowpea, which showed a significant delay in borer colonization.

Discussion and Conclusions

As wide-scale practices, postharvest tillage, chopping and storing sorghum stalks in small pieces, removal of deadhearts, partial burning of the stalks, and destruction of stalks and stubble have all been found effective as cultural practices in reducing borer populations. Time of sowing, crop rotation, tillage, plant spacing, water and fertilizer management, mulching, and intercropping all contribute useful practices which also afford cultural control of sorghum stem borers.

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Biological Control of Sorghum Stem Borers

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Abstract

All the sorghum stem borers are polyphagous Pyralids and Noctuids which attack most tropical cereals. In developing countries, the biological control of these pests is directed at rice, maize, or sugarcane rather than sorghum. Attempts have been made to reduce their population levels by releasing indigenous or introduced natural enemies. Several species ha ve now become established although little is known about the economic implications of these introductions. The potential use of pathogens in the biological control of stem borers is also discussed.

Résumé

***Lutte biologique contre les foreurs des tiges :** Tous les foreurs des tiges du sorgho sont des pyrales et des noctuelles polyphages qui attaquent la plupart des céréales tropicales. Dans les pays en développement ce sont les cultures de riz, de maïs ou de canne à sucre, plutôt que celles de sorgho, qui bénéficient de la lutte biologique. Des tentatives ont eu lieu pour réduire les populations de ravageurs en liberant des ennemis naturels, indigènes ou introduits. Plusieurs espèces se sont déjà implantées mais on connaît mal les conséquences économiques de ces introductions. Les potentialités des agents pathogènes dans la lutte biologique contre les foreurs des tiges sont également étudiées.*

Introduction

In all the regions of the world where sorghum is cultivated, this graminaceous crop is attacked by lepidopterous stem borers. These are Pyralidae or Noctuidae which are generally polyphagous. The species of genera *Chilo, Sesamia,* and *Diatraea,* cited by Seshu Reddy (1985), attack at least three of the main graminaceous crops throughout the tropics and subtropics (rice, corn, millet, sorghum, and sugar cane) and also find suitable hosts in many wild grasses. Most of these insects survive under wide-ranging climatic conditions and have been recorded throughout the tropic and semi-tropic regions of the world.

Diatraea saccharalis is present in the southern region of United States, and in Central and South America. *Eldana saccharina* and *Sesamia calamistis* are found in Africa south of the Sahara and tolerate dry or wet seasons. Severe damage has been caused by *Chilo partellus* in Nepal, South Africa and in all the Indian climatic regions.

Sesamia calamistis and *E. saccharina* multiply throughout the year and their successive generations attack cultivated host plants during the rainy season(s), then survive on wild grasses. Other stem borers enter into diapause or quiescence with the onset of the dry season, such as *Busseola fusca, Acigona ignefusalis, C. partellus,* or *D. saccharalis.*

Several species of sorghum stem borers can cohabit the same plant, with some attacking young stems and others concentrating around the plant internodes and ears. This location specificity causes different kinds of damage: the stem is destroyed because the central shoot is killed, causing deadheart, or the stem is broken at the level of a bored internode; or the productivity of the ear is reduced

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because the host plant is weakened or because a part of the ear has been directly destroyed by larvae.

Agricultural research and development institutions, with a mandate to improve sorghum production techniques and insect-pest management in developing countries, have directed efforts toward an integrated approach, particularly one which incorporates biological controls.

Results of Biological Control of Sorghum Stem Borers

Conditions of Bio-control Attempts

Biological control of sorghum stem borers has often been considered to be part of a strategy for graminaceous crop protection in tropical countries. For example, the purpose of most introductions of parasites of *D. saccharalis* has been to protect sugar cane against this stem borer in many countries of the American continent. In the same way, attempts to establish natural enemies of *C. partellus in* India and Africa had the primary objective to control this stem borer in maize plantations. But biological control also involves safeguarding or enhancing indigenous beneficial insects, so any changes in agronomic practices influencing their well-being warrants study.

Biological Control with Entomophagous Insects

Parasites and Predators

Many parasites of different families have been recorded in Asia, Africa, and the Americas from the five main sorghum stem borers: *C. partellus, B. fusca, Sesamia* spp, *E. saccharina,* and *D. saccharalis* (Table 1). Three families of larval parasites predominate: Braconidae, Ichneumonidae, and Tachinidae.

Braconids account for 35% of parasites recorded on *C. partellus* and 45% of parasites found on *D. saccharalis.* Only 4 out of 48 species of this family which have been identified, are recorded as parasites of two stem borer species, at least among the five cited above. Only three species, after their introduction and their establishment, are actually present in two regions : Africa and America.

In Africa, 5 of 11 braconid species, 3 of 9 ichneumonid species, and 6 of 11 tachinid species recorded

Table 1. Parasites of sorghum stem borers.

Families of parasites	Species of stem borers[1]				
	CP	BF	SSP	ES	DS
Braconidae	14	8	4	1	21
Ichncumonidae	9	6	4	2	3
Trichogrammatidae	1	-	-	2	5
Pteromalidae	-	-	1	-	2
Eulophidae	3	3	2	2	1
Eurytomidae	1	-	-	1	1
Eupelmidae	-	-	-	-	2
Chalcididae	3	1	2	2	1
Scelionidae	1	2	1	1	1
Bethylidae	2	-	-	2	1
Tachinidae	7	10	3	7	10

1. CP = *Chilo partellus;* BF = *Busseola fusca;* SSP = *Sesamia* sp; ES = *Eldana saccharina;* and DS = *Diatraea saccharalis.*

are common parasites to at least two of five main African stem borers. These data clearly show that the possibilities of introducing more exotic parasites of graminaceous stem borers are not exhausted, even if previous attempts have not proven successful in India, America, and Africa.

Scant information is available on other stem borer predators. Many species of ants are predators of eggs and newly hatched larvae of *E. saccharina* (Betbeder-Matibet 1983; Leslie 1982; and Girling 1978). Sharma and Sarup (1979) reported the role of different spiders and Seshu Reddy (1981) the contribution of ants, ladybird beetles, and earwigs in killing populations of *C. partellus.* Temerak (1983) reported that several soil-inhabiting predators destroy nymphal populations of *Sesamia cretica.*

Review of Some Bio-control Attempts

On the American continent, various attempts of biological control with parasites were made in different sugarcane areas during the last 30 years to control *D. saccharalis.* Few were successful. Two notable successes were obtained with *Lixophaga diatraeae,* which became established in some Caribbean Islands, and *A. flavipes,* which became established in Barbados, South America, and the United States. Although these introductions were designed for integrated protection of sugarcane plantations, sorghum cultures have benefitted from these parasite releases.

In Africa, attempts to introduce enemies of graminaceous stem borers have met with varying success during the last 20 years. In Kenya, Uganda, and Tanzania, several species of Trichogrammatidae, Braconidae, Ichneumonidae, and Tachinidae have been imported from India and released. None have been recovered (Ingram 1983). In South Africa, *A. flavipes* was introduced recently (Zkoroszewski and Van Hamburg 1987) then released in maize and sorghum infested by *C. partellus* and *B. fusca.* This braconid was recovered on both pests, some years after releasing, but apparently has not been able to maintain populations. Unlike *Apanteles sesamiae,* it seems that *A. flavipes* has not endured the climatic conditions of austral winter.

Some indigenous parasites have been found to reduce larval and nymph populations of *E. saccharina* (Betbeder-Matibet 1983). But most laboratory tests with other parasites of pyralidae were failures. The braconids *A. flavipes, Apanteles chilonis* or *Bracon chinensis,* the techinids *L. diatraeae, Sturmiopsis inferens* or *Metagonistylum minense* do not thrive on larvae of this African stem borer. The nymphs of *E. saccharina* are well-protected by a thick cocoon and are not parasitized by the eulophid *Pediobus furvum.*

In Madagascar and in the Mascareignes Islands, the sorghum stem borers *C. partellus, C. orichalcociliellus,* and *S. calamistis* are found. Here and on the continent, their populations are decimated by a cohort of indigenous parasites (Appert and Ranaivosoa 1971). But several exotic parasites, have also been introduced, released, then recovered (Appert, et al. 1969). *A. sesamiae,* from Mauritius, has been released in Madagascar and Reunion where it became established, parasitizing the larvae of *S. calamistis.* From Uganda, *P. furvum,* has been released in Madagascar, Reunion, and the Comores Islands. Now it is recovered from nymphs of *S. calamistis* and *C. partellus.* The eulophids *Trichospilus diatraeae* and *Tetrastichus israeli* were also released in Reunion and recovered on the pink borer *S. calamistis.*

Importance of the Safety of Beneficial Organisms

Outbreak of insect infestations in the field is often the result of human interventions which modify the biological balance of the agrobiocoenose. New varieties, cultural practices, or a decision to use chemical control, for example, can create new ecological situations and cause an unexpected multiplication of a pest.

As we know, the graminaceous stem borer populations can be decimated by parasites and predators. Several authors note that ants and spiders are principally responsible for the mortality (sometimes exceeding 90%) of eggs and newly hatched larvae of Pyralidae and Noctuidae. For example Leslie (1982) notes that 60% of *E. saccharina* eggs are killed in experimental plots without soil treatment while only 19% mortality occurs in plots with soil treatment.

In Burkina Faso, a nematicide experiment on plantation sugarcane confirmed the prominent part played by predators in the natural control of *E. saccharina.* Table 2 shows various soil treatments applied in a randomized experiment and 12 months later, percentages of bored internodes in the plots. These percentages reveal survival rates of *E. saccharina* populations after egg incubation, and the development of newly hatched larvae before stalk internode penetration.

The nontreated control percentage (3.9%) is equal to the infestation level in sugarcane plantations in the experiment area. With methyl bromide applied under a sheet, biological activity is stopped. In this case, 21.8% of plant internodes were bored. With the other three soil treatments, damage by *E. saccharina* is more serious than in the nontreated control only when nematicides are applied at high rates.

This experiment has indicated the real importance of natural control of eggs and newly hatched larvae of this stem borer. Without soil predators, damage to sugarcane can be five times greater. In sorghum

Table 2. Incidence of soil treatment[1] on natural control of *Eldana saccharina.*

Treatment	(a.i. m^{-2} ha^{-1})[2]	% Bored internodes[3]
Methyl bromure	100 g m^{-2}	21.8
Aldicarbe	4.0 kg ha^{-1}	4.9
Phenamiphos	2.8 kg ha^{-1}	4.1
Phenamiphos	5.6 kg ha^{-1}	3.9
Phenamiphos	8.4 kg ha^{-1}	9.9
Carbofuran	3.0 kg ha^{-1}	5.2
Carbofuran	6.0 kg ha^{-1}	7.1
Carbofuran	9.0 kg ha^{-1}	8.0
Untreated control	-	3.9

1. In a nematicide experiment on sugarcane.
2. Active ingredient applied on 1 m^2 or 1 ha.
3. Average of 6 replications of 20 stalks each.

stem borer management, conservation of useful soil fauna should be a recognized precaution before considering transfer and release of imported natural enemies into sorghum areas.

Biological Control with Fungal, Bacterial, and Viral Diseases

Few diseases have been identified on sorghum stem borers and their value as biological control agents is generally unknown. A few examples of recent research in this area are given below.

Some laboratory and field experiments have been carried out to evaluate the pathogenic behavior of fungal, bacterial, and viral diseases. The effect of a chromogenic strain of *Serratia marcescenswas* studied on *C. partellusin* India (Chakravorty et al. 1983). A single application of the cell suspension of the bacterium prevented eggs from hatching and killed newly hatched larvae. Sinha and Prasad (1975) think that toxin of *Fusarium aleyrodis* could be used against this stem borer.

Interactions between parasitoids and pathogens in the same host have also been observed, in order to know if there is synergy or competition between parasites. This work is underway with *S. calamistis* with *A. sesamiae* and two viruses. Other laboratory trials have been undertaken to investigate the transmission of pathogens by parasitoids, for example, in *Sesamia cretrca* (Temerak 1982).

In northern Florida, Funderburk et al. (1984) report granulosis virus and *Beauveria* sp on larval *Elasmopalpus lignosellus.* In Reunion, a viral complex, including nuclear and cytoplasmic polyhedrosis viruses, has been detected on *S. calamistis* larvae.

But very few pathogens have been tested under field conditions and the experiments noted here have not yet resulted in an improvement of integrated pest management programs in sorghum.

Conclusions

Resources allocated for biological control of graminaceous stem borers, and especially sorghum stem borers in tropical countries, have been too small to permit a good survey of natural enemies. While a number of parasites of eggs, larvae, and pupae of these stem borers are known, very few predators and pathogens have been identified. Nor has their efficacy been tested against pyralids and noctuids. We know that many nosema diseases destroy populations of stem borers in Africa *(Chilo partellus, Chilo zacconius,* and *Sesamia calamistis)* but their epidemiology and their relative efficiency have not been studied. While some excellent work has been carried out on biological controls of sorghum stem borers, their predators and diseases (which can kill more than 90% of borer populations) have been largely neglected. Insect pest management research in these areas needs amplification.

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Assessment of Yield Loss of Sorghum and Pearl Millet due to Stem Borer Damage

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Abstract

The stem borer species that infest sorghum and pearl millet are listed. At 1CRISA T Center in India, loss in grain yield due to Chilo partellus *damage in sorghum was estimated by two methods. These experiments involving the phased use of carbofuran, or artificial infestation using laboratory-reared first instar larvae showed that maximum grain yield loss occurred when infestation took place 15-30 days aftercrop emergence. The maximum number of deadhearts was formed when infestation took place during this period. Stem tunneling caused by later infestations did not cause a reduction in grain yield.*

In two studies at the ICRISAT Sahelian Center in Niger, results showed that under low levels of borer infestation (caused by Coniesta ignefusalis*), a nonprotected pearl millet crop gave slightly higher yields than one that was protected by insecticide. In a date of sowing trial losses were heavier on late-sown millet with an increase in proportion of nonproductive tillers. Yield loss caused by other borer species are also discussed.*

Résumé

Estimation de la baisse de rendement du sorgho et du mil due aux dégâts causés par les foreurs des tiges : *Les différentes espèces de foreurs des tiges infestant le sorgho et le mil sont répertoriées. Au Centre ICRISAT en Inde, la baisse de rendement en grain de sorgho due à* Chilo partellus *est déterminée de deux manières, soit par l'application échelonnée de carbofuran, soit par une infestation artificielle en utilisant des larves de premier stade élevées au laboratoire. Les pertes sont maximales lorsque l'infestation a lieu entre 15 et 30 jours après la levée. C'est pendant cette période que le nombre de coeurs morts est le plus élevé. Les galeries creusées lors d'infestations plus tardives n'entraînent pas de réduction du rendement en grain.*

*Deux études menées au Centre sahélien de l'ICRISAT au Niger ont montré que, pour de faibles niveaux d'infestation d'*Acigona ignefusalis, *une culture de mil non protégée par des insecticides a donné un rendement légèrement supérieur à celui d'une culture traitée. Dans un essai de date de semis, les pertes étaient plus importantes sur une culture de mil semée tardivement, avec une augmentation du pourcentage de talles non productives. La baisse de rendement due à d'autres espèces de foreurs est également étudiée.*

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Introduction

Out of 27 species of stem borers that attack sorghum crops, *Chilo partellus* Swinhoe is the predominant species in Asia and East Africa. Prominent in other regions are: *Busseola fusca* Fuller, *Sesamia calamistis* Hampson, and *Eldana saccharina* Walker in Africa; *Sesamia cretica* Laderer in Mediterrarean Europe and the Middle East; and *Diatraeaspp* in the southern U.S., Mexico, and New World Tropics (Young 1970, FAO 1980). In pearl millet, the predominant species of stem borer is *Coniesta* (*Acigona) ignefusalis* Hampson, which is a major pest in West Africa.

Assessment of crop losses due to insect attack is essential in determining pest status, economic threshold levels, and suppression strategy options for pest control. It is also a tool in decision making in agricultural planning and forecasting. Although severe stem borer infestations in sorghum and pearl millet have been reported from a number of locations, there are no reliable qualitative estimates of resultant crop losses. Several methods have been used in an attempt to estimate crop losses due to insect attack. These include visual damage scores, comparing yield from fields having different levels of natural infestation, comparing yield of individual plants with and without infestation, and comparing yield of chemically protected and nonprotected plots. Another method involves releasing insects in varying number per plant or plot and correlating damage/yield with insect density. This method has also been used in comparing yield of resistant and susceptible varieties under insect infestations (Walker 1983). Two studies on yield loss estimation are reported in this paper. The first involves the spotted stem borer, *C. partellus* in sorghum at ICRISAT Center in India, and the second is on the millet stem borer, C. *ignefusalis* in pearl millet at the ICRISAT Sahelian Center in Niger.

Materials and Methods

Sorghum

Yield loss in sorghum due to stem borer (C. *partellus)* attack was estimated by two methods: protecting the crop from stem borer infestation at different growth stages by insecticide application (Carbofuran 3G) in the leaf whorl; and infesting the crop with eggs and larvae at different growth stages. The first experiment was conducted under natural borer infestation at Hisar, India, from 1982 to 1985. The second experiment was conducted at ICRISAT Center in 1985 and 1986. Eggs and larvae were obtained from ICRISAT's insect rearing laboratory, where the insect is reared on artificial diet.

Natural infestation. Natural infestation of stem borer at Hisar is usually severe on sorghum planted during the first half of July (Taneja and Leuschner 1985). Sorghum was sown for these trials during this period in each of the study years. During 1982-83, only genotype CSH 1 was used. In 1984, three genotypes, CSH 1, ICSV 1, and IS 2205 were used, and in 1985 two genotypes, ICSV 1, and PS 28157-1 were included. Planting was done in 8-row plots of 4 m length. In 1982 and 1983, a randomized block design was used, while in 1984 and 1985 a split plot design was used with genotypes as main plots.

Carbofuran granules (2 g meter row^{-1}) were applied at 15, 30, and 45 days after emergence (DAE) in various combinations to obtain the protection levels indicated in Tables 1-3. Total number of plants and those showing deadhearts in the central four rows of each plot were counted 45 DAE. At harvest, the number of harvestable panicles were recorded, sun dried and threshed, and grain mass was recorded. From each plot, 50-100 stems were split open and stem tunneling was recorded.

Artificial infestation. Stem borer infestation on sorghum is very low during the rainy season at ICRISAT Center. Uniform infestation is obtained by using eggs or first-instar larvae reared on artificial diet (Taneja and Leuschner 1985). For larval infestation, a split-split plot design was used in both years with genotypes ICSV 1 and PS 28157-1 planted in the main plots. Subplots within the main plots were infested at 15,20,30,40, and 50 DAE. Within these subplots, insect density was varied in subplots. Insect density per plant was tested at 0,4,8,12 in 1985, and 0,1,2,4,8,12 in 1986. Each sub-subplot consisted of 3 rows of 4 m length. All plants in the central rows were infested with a specified number of first-instar larvae. A selected number of larvae (noted above for each year) were gently mixed with a carrier (poppy seeds) and introduced in the leaf whorl to initiate infestation.

For egg infestation, a split-plot design was used in 1985 with genotype ICSV 1 and infestation stages of 15,20,30,40, and 50 DAE were established as main plots. Insect density of 0,10,20,33 and 50% plants infested with single egg masses were established as subplots. In 1986, a split-split plot design was used

Table 1. Effect of protection levels on stem borer infestation, grain yield, and avoidable losses in sorghum, Hisar, rainy seasons 1982-83.

	1982			1983		
Treatment	Dead hearts (%)	Grain yield (t ha^{-1})	Avoidable loss (%)[1]	Dead hearts (%)	Grain yield (t ha^{-1})	Avoidable loss (%)
Protection between						
15-60 DAE[2]	10.5	3.70	0.0	9.5	2.33	0.0
15-45 DAE	8.2	3.40	8.1	12.4	2.00	14.2
15-30 DAE	20.3	2.93	20.8	21.8	1.74	25.3
Zero protection	62.2	1.08	70.8	60.1	1.01	56.6
SE	±2.98	± 0.126		±3.79	±0.147	
CV (%)	17	8		23	17	

1. $\text{Avoidable loss (\%)} = \frac{\text{Yield in intensive protected plot} - \text{Yield in a particular treatment}}{\text{Yield in intensive protected plot}} \times 100$
2. DAE denote days after crop emergence.

with genotypes ICSV 1 and PS 28157-1 as the main plots, infestation stages as subplots and insect density as sub-subplots. Plot size was 8 rows of 4 m length and the central 4 rows were infested with a specified number of egg masses. Each egg mass, containing 50-60 eggs was stapled at the top fourth leaf.

Observations on leaf damage were recorded one week after infestation. Total number of plants and those showing deadhearts were recorded three weeks after infestation. At harvest, harvestable panicles on main stems and tillers were counted in the infested rows. These panicles were dried and threshed, and grain mass was recorded. Stem tunneling was also recorded at harvest by splitting open 50 stems from each plot.

Pearl Millet

Date of sowing trial. The relationship between crop age, date of sowing and extent of crop damage by *C. ignefusalis* in pearl millet was investigated in field trials at the National Agricultural Research Station, Kamboinse, Burkina Faso, in 1981 and 1982, and at the ICRISAT Sahelian Center, Sadore, Niger in 1984 and 1985. Three varieties were used in each trial: Nigeria Composite, Ex-Bornu, and a local cultivar at Kamboinse; and HKBtif, CIVT, and a local cultivar at Sadore. Four replications of a randomized split- plot design were set up with sowing dates as main plots and cultivars as subplots (5m x 5m). Observations on borer infestation were recorded at 35 days after sowing (DAS), 50 DAS, and at harvest.

Insecticide trial. Quantitative estimates of yield loss in millet were determined in 1985 by using paired comparisons of insecticide-protected and nonprotected plots. Two varieties, Nigeria Composite and a local cultivar, were sown in a randomized split plot design in six replications with varieties as main treatments and insecticide application of Rogor® (dimethoate, 500g a.i. ha^{-1}) as subtreatments. The first insecticide treatment was applied at 15 DAS and subsequently at two-week intervals for a total of four applications. Observations on borer infestation were recorded at 35 and 50 DAS, and at harvest from an effective area of 5m x 5m within subplots of 8m * 8m. Grain yield from harvested panicles was recorded after sun-drying and threshing.

Results and Discussion

Sorghum

Natural infestation. During 1982 and 1983, when only genotype CSH 1 was used, stem borer infestation in control plots (no protection treatment) was 60 and 62% (Table 1). Grain yield in fully protected treatments was 3.7 t ha^{-1} in 1982 and 2.33 t ha^{-1} in 1983. Avoidable loss, calculated on the basis of grain yield obtained through intensive protection and no

Table 2. Effect of protection levels on stem borer infestation, grain yield, and avoidable losses in sorghum, Hisar, rainy season 1984.

	CSH 1			ICSV 1			IS 2205		
Treatment	Dead-heart <%)	Grain yield (t ha-1)	Avoidable loss[1] (%)	Dead-heart (%)	Grain yield (t ha-1)	Avoidable loss (%)	Dead-heart (%)	Grain yield (t ha-1)	Avoidable loss (%)
Protection between									
15-60 DAE[2]	25.2	5.17	0.0	28.0	4.24	0.0	33.9	1.87	0.0
15-45 DAE	23.8	4.39	15.1	49.0	2.64	37.7	37.6	1.28	31.6
15-30 DAE	39.2	4.79	7.4	50.2	2.62	38.2	30.6	1.91	0.0
30-60 DAE	61.1	3.11	39.8	75.9	0.76	82.1	43.2	1.18	36.9
30-45 DAE	53.7	3.70	28.2	79.0	0.74	82.5	43.0	1.04	44.4
45-60 DAE	95.1	1.60	69.1	100.0	0.33	92.2	47.6	0.90	51.9
Zero Protection	100.0	0.19	96.3	100.0	0.00	100.0	55.5	0.75	59.9
SE	± 3.46	± 0.259		±3.46	± 0.259		± 3.46	± 0.259	
CV (%)	18	26		18	26		18	26	

1. Avoidable loss (%) $= \frac{\text{Yield in intensive protected plot} - \text{Yield in a particular treatment}}{\text{Yield in intensive protected plot}} \times 100$

2. DAE denotes days after emergence.

protection, ranged between 56.6 and 70.8% in two years. Maximum grain yield was obtained when the crop was protected between 15 and 60 DAE, however, maximum differences in yield levels were recorded between zero protection and early stages of protection (15-30 DAE).

In 1984, with increase in protection level treatments, different levels of stem borer infestation and corresponding grain yields were noticed in all three genotypes tested (Table 2). In susceptible genotypes CSH 1 and 1CSV 1, 100% infestation was observed and negligible grain yield was realized in zero-protection treatment. In resistant genotype IS 2205, however, maximum infestation was 55.5% and some grain yield was obtained (0.75 t ha-1). Although under protected conditions, CSH 1 and ICSV 1

Table 3. Effect of protection levels on stem borer infestation, grain yield, and avoidable losses in sorghum, Hisar, rainy season 1985.

	ICSV 1			PS 28157-1		
Treatment	Dead hearts (%)	Grain yield (t ha-1)	Avoidable loss (%)[1]	Dead hearts (%)	Grain yield (t ha-1)	Avoidable loss (%)
Protection between						
15-60 DAE[2]	15.9	3.57	0.0	6.4	4.45	0.0
15-45 DAE	8.1	2.32	35.0	4.1	3.26	26.7
15-30 DAE	19.5	2.68	24.9	6.7	3.35	24.7
30-60 DAE	36.5	0.72	79.8	14.7	1.68	62.2
30-45 DAE	36.6	0.84	76.5	16.7	1.21	72.8
Zero protection	80.3	0.01	99.7	45.7	0.73	83.6
SE	±4.66	±0.667		±4.66	±0.667	
CV (%)	26	16		26	16	

1. Avoidable loss (%) $= \frac{\text{Yield in intensive protected plot} - \text{Yield in a particular treatment}}{\text{Yield in intensive protected plot}} \times 100$

2. DAE denotes days after emergence.

yielded significantly higher than the resistant genotype; under zero protection IS 2205 outyielded both susceptible genotypes. Maximum infestation and grain yield differences were obtained between zero-protected and early protected (15-30 DAE) treatments, which were similar to the 1982-83 results.

In 1985, 80% deadhearts were recorded on susceptible ICSV 1 compared with 45.7% on resistant PS 28157-1 in zero-protected treatments (Table 3). Here again, in zero-protected treatment, there was no grain yield in the susceptible genotype, while some yield was obtained from the resistant genotype even under no protection. Minimum avoidable losses were observed when the crop was protected between 15 and 30 DAE.

Four years of data on the effect of protection levels indicates that the maximum control of stem borer, and subsequently higher grain yield was obtained when the crop was protected between 15 and 30 DAE. This is the crop stage at which borer infestation results in deadheart formation, which is the primary damage symptom related with grain yield reduction (Taneja and Leuschner 1985). There was no trend observed in stem tunneling as a parameter influencing yield within different protection levels in any of the genotypes tested during 1983-85.

Artificial infestation. Stem borer infestation (deadhearts) and grain yield with various borer densities, at different stages of infestation during 1985, are presented in Figure 1. Infestation at 15 DAE resulted in maximum damage and subsequent yield reduction in both resistant PS 28157-1 and susceptible ICSV 1 genotypes. At this stage of infestation, there was no significant difference between various borer densities (4,8, and 12 larvae plant^{-1}) in terms of damage and grain yield for either genotype. However, infestations at 20 DAE showed linear increase in borer damage and decrease in grain yield, as insect density increased. In resistant genotypes, infestation was lower at all borer densities and corresponding grain yields were higher than in the susceptible genotype. Infestations carried out 30 DAE, and later, did not result in deadheart formation; however, grain yield decreased in infested plots at 30 DAE. At 40 DAE infestation, there was no decrease in grain yield.

In 1986, similar infestations and grain yield reductions resulted when 4,8, and 12 larvae were introduced per plant. However, with the inclusion of two more infestation levels (1 and 2 larvae per plant), some trend was observed even at 15 DAE infestations (Fig. 2). Deadheart expression decreased as the infestation was delayed. Avoidable losses increased with the increase in borer density and decreased as the infestation was delayed (Table 4). Also, avoidable losses were lower in resistant genotypes than in

Table 4. Estimation of avoidable losses due to stem borer infestation in sorghum, ICRISAT Center, rainy season 1986.

	Avoidable loss (%)[1]					
	ICSV 1			PS 28157-1		
Insect density	15 DAE[2]	20 DAE	30 DAE	15 DAE	20 DAE	30 DAE
Larval infestation (Larvae plant^{-1})						
1	31.7	28.0	25.2	13.1	15.9	3.0
2	48.0	38.4	41.1	29.3	28.1	9.8
4	70.2	41.2	43.0	45.9	31.1	9.8
8	86.5	54.4	55.6	79.9	50.5	24.8
12	84.9	56.8	58.9	86.1	48.3	28.6
Egg infestation (% plants with eggs)						
10	23.4	21.3	15.3	22.0	5.5	2.2
20	52.3	37.8	25.9	41.4	20.9	14.9
33	69.3	53.0	32.2	48.9	22.8	22.4
50	61.5	59.1	51.4	57.3	39.0	36.8

1. $$\text{Avoidable loss (\%)} = \frac{\text{Yield in intensive protected plot} - \text{Yield in a particular treatment}}{\text{Yield in intensive protected plot}} \times 100$$

2. DAE denotes days after emergence.

the susceptible genotypes in almost all treatments.

With egg infestation, borer damage was less than that incurred with larval infestation. Even with 50% plants infested with egg masses 15 DAE, the maximum damage was 68% deadhearts in ICSV 1 and 59% in PS 28157-1 (Fig. 3). There was a linear relationship between damage and borer density: increase in borer density increased damage, and correspondingly decreased the grain yield. Resistant genotypes showed less borer damage and higher grain yield in all the treatment levels. With egg infestation, as in larval infestation, borer damage decreased as the infestation was delayed. Similarity, avoidable losses increased as borer density increased, and decreased as infestation was delayed (Table 4).

Data from natural and artificial infestation indi-

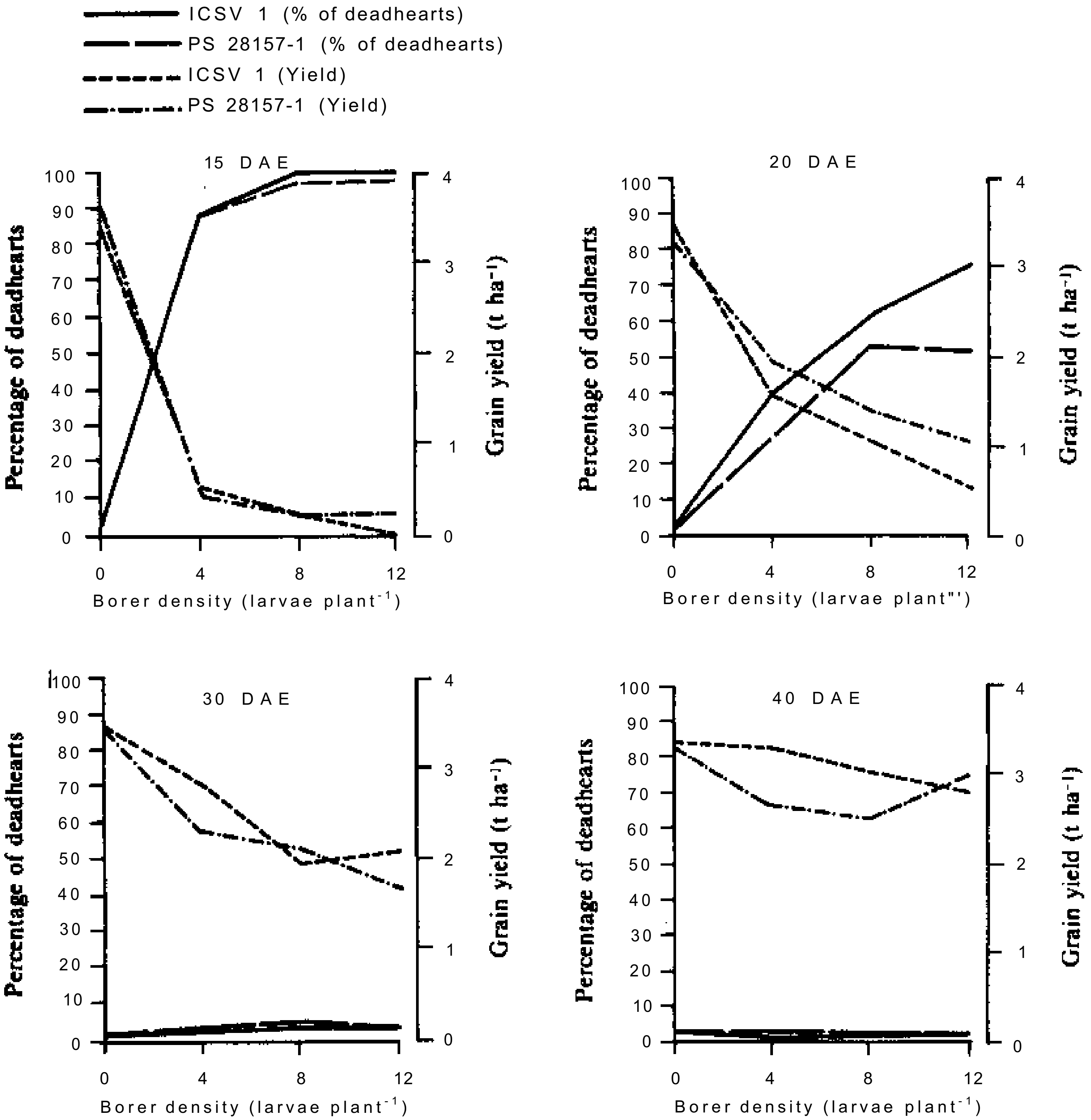

Figure 1. Relationship between stem borer density, infestation, and yield under artificial infestation, ICRISAT Center, rainy season 1985.

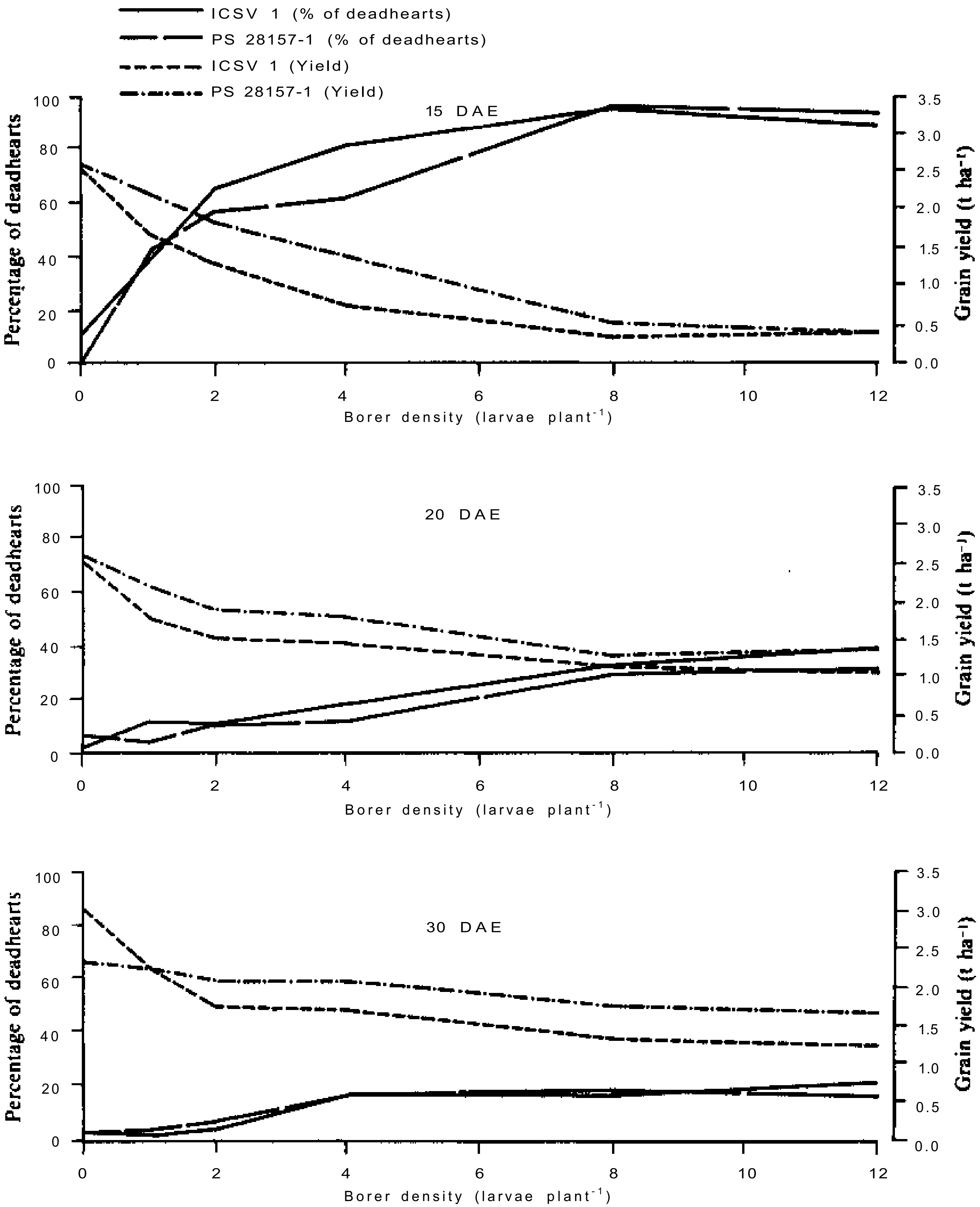

Figure 2. Relationship between stem borer density, infestation, and grain yield under artificial infestation using larvae, ICRISAT Center, rainy season 1986.

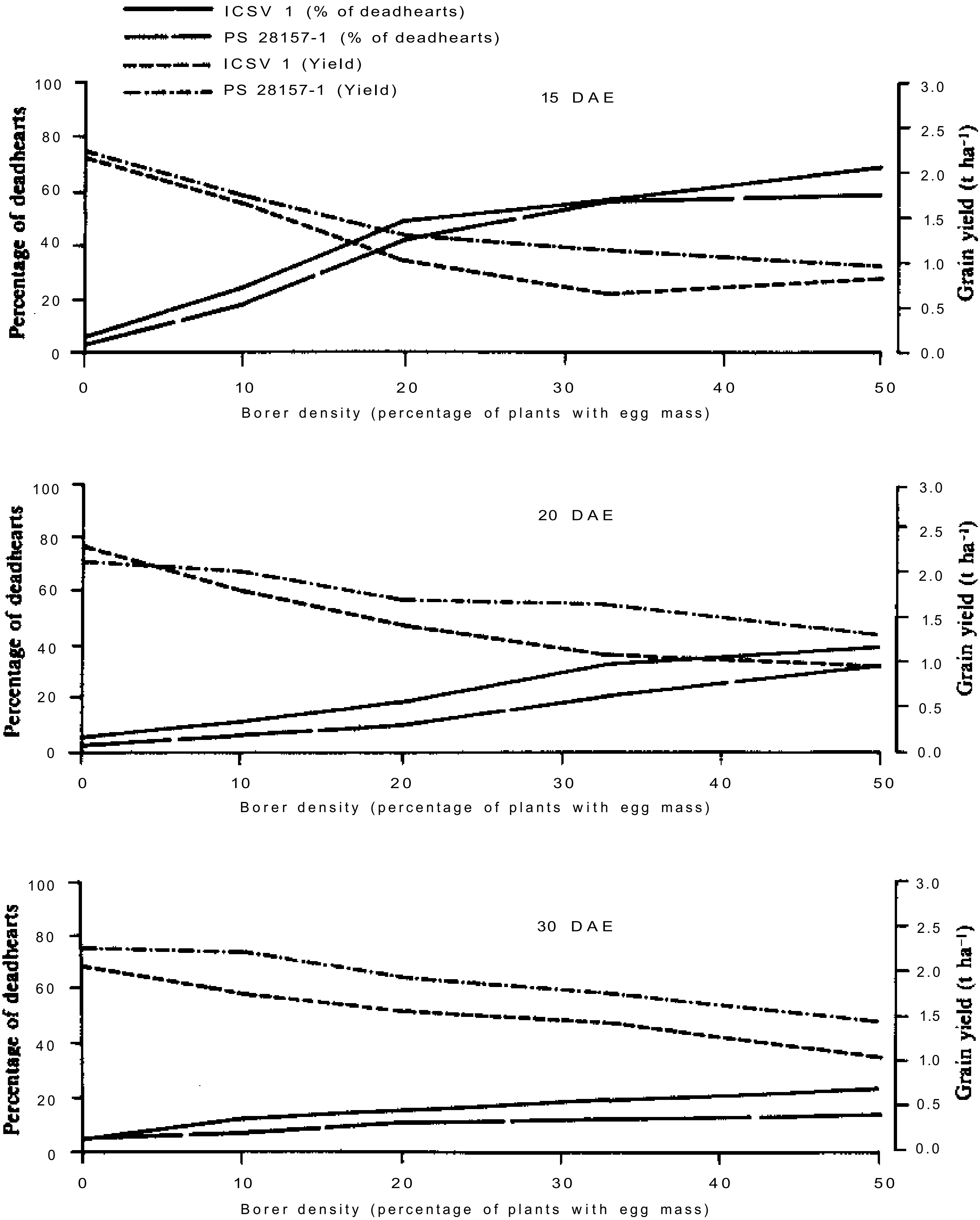

Figure 3. Relationship between stem borer density, infestation, and grain yield under artificial infestation using egg masses, ICRISAT Center, rainy season 1986.

cates that early infestation by stem borer is crucial, results in deadheart formation, and causes grain yield reduction. This has also been observed by Singh et al. 1968, and Taneja and Leuschner 1985.

Pearl Millet

Date of sowing trial. Initial crop damage caused by *Coniesta* infestation is usually observed as deadhearts of seedlings, attributed to feeding activities of young larvae of the first generation (Harris 1962). Leaf feeding symptoms have not been recorded in this species.

At Kamboinse and Sadore, there were no significant differences between varieties in deadheart formation but differences were observed between sowing dates, with the late crop showing a higher proportion of deadhearts than the early crop. At both locations, stem damage increased with a delay in sowing.

Tiller infestation and internode damage were much higher on the third-sown crop (mean of 84.3 and 44.3% at Kamboinse; 84.7 and 40.8% at Sadore) than on the first crop (mean of 64.8 and 2.6% at Kamboinse, 26.5 and 1.5% at Sadore). Grain yield data were confounded by bird damage but data collected on tiller productivity also indicated a corresponding increase in nonproductive tillers with a delay in sowing.

Insecticide trial. Although planted in mid-June 1985, this trial experienced a low level of borer infestation. No significant differences were observed in crop damage within varieties for the insecticide protected and nonprotected treatments (Table 5). However, between varieties, Nigeria Composite was infested more than the local cultivar. It was also observed that low levels of borer infestation resulted in a slight yield increase of the nonprotected treatment over the control (Nigeria Composite 11.9%, Sadore local 1.3%). Similar results were obtained earlier by Harris (1962), although in a separate experiment with high levels of borer attack he recorded a grain yield loss of 15%.

Conclusions

In sorghum, maximum control of stem borer infestation was obtained when the crop was protected between 15 and 30 DAE by the application of carbofuran granules in the leaf whorls. This protection also afforded significantly higher grain yields. Under artificial infestation, resistant genotypes showed a consistent advantage in avoiding grain yield loss. Infestations at 15 DAE resulted in maximum damage and subsequent yield reductions in all genotypes tested. Data from both natural and artificial infestation indicates that early infestation by stem borer is the most damaging and results in greatest reduction of yield.

With pearl millet, trials in Burkina Faso and Niger have shown that early sowing results in greater tiller productivity and higher yields. Trials with insecticide control proved inconclusive in estimating yield loss in millet. Additional work in this area might be useful.

Table 5. Assessment of crop loss caused by infestation of *Coniesta ignefusalis* in two millet cultivars, Sadore, Niger 1985.

	Cultivar/treatment				
	Nigeria Composite		Sadore Local		
Parameters measured	Protected control	Non-protected	Protected control	Non-protected	Mean ± SE
No. of larvae/stem (50 DAS[1])	1.5	3.0	0.0	0.2	1.2 ± 0.72
Infested stems (%) (50 DAS)	8.3	10.0	1.7	3.3	5.8 ± 2.10
Internodes tunneled (%) (50 DAE[2])	1.4	2.6	0.3	0.6	1.2 ± 0.60
No.of larvae/stem (at harvest)	11.5	11.2	6.3	7.5	9.1 ± 1.49
Infested stems (%) (at harvest)	28.0	37.3	17.3	23.0	26.4 ± 2.87
Internodes tunneled (%) (at harvest)	4.9	8.5	2.6	3.4	4.8 ± 0.52
Grain yield (kg ha^{-1})	1856	2076	1414	1432	1720 ± 372
Yield loss (%)	11.9[3]		1.3		

1. DAS denotes days after sowing.
2. DAE denotes days after emergence.
3. Indicates yield advantage of nonprotected over protected control.

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Management Options for Sorghum Stem Borers for Farmers in the Semi-Arid Tropics

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Abstract

Currently recommended control measures against sorghum stem borers are briefly reviewed. Generally, successful methods applied in developed countries have been tested at research stations in developing countries and recommended to farmers in the semi-arid tropics. The extent of their use by farmers is assessed and farm-and sector-level constraints to adaptation are evaluated. Past research leading to control recommendations did not adequately take local farming practices into account. An approach for farmer-oriented research on control methods is suggested.

Résumé

***Différentes options proposées aux paysans des zones tropicales semi-arides pour la lutte contre les foreurs des tiges du sorgho :** Les techniques de lutte recommandées actuellement pour lutter contre les foreurs des tiges du sorgho sont rappelées. En général les méthodes appliquées avec succès dans les pays développés ont été testées dans les stations de recherche des pays en développement et proposées ensuite aux paysans dans les zones tropicales semi-arides. Le degré de leur adoption par les paysans est évalué ainsi que les contraintes pour leur usage au niveau des champs paysans. Les recherches menées antérieurement en matière de lutte n'ont pas suffisamment pris en compte les pratiques culturales locales. Une approche est proposée pour une recherche orientée au milieu paysan sur les techniques de lutte.*

Introduction

Literature abounds with information on the control of sorghum pests, and much of it deals with stem borers. Recommendations for stem borer management range from the simple cultural practice of sowing date, to chemical and biological control, modern resistant genotypes, and more ambitious integrated pest management. However, very few farmers of the semi-arid tropics (SAT) practice these recommendations, which gather dust in libraries.

Specific research has not been conducted on the adoption by farmers of stem borer management recommendations. Prerequisites to the success of any pest-control technology, and thus the success of any stem borer management research program have been identified by Reichelderfer and Bottrell (1985, p.284): "Basically any pest-control technology must meet four criteria before it can be considered a likely candidate for acceptance and overall effectiveness: it must be politically practical, socially acceptable, and economically feasible, as well as technically effective."

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Traditional research concentrates on the technical effectiveness of pest management recommendations, usually neglecting or ignoring other criteria vital for success. This emphasis on technical feasibility often results in pest control recommendations that can, at best, be adopted only by progressive farmers. Progressive researchers should, ideally, take all four criteria into account so that their recommendations can be adopted by traditional farmers in the SAT.

In this paper we explore some implications of adopting a farming systems perspective in stem borer management research in an attempt to increase the utility of the research output for farmers. The essence of this approach is that by spending more effort on anticipating the consequences of management practices that are important for farmers, we reduce the chance of recommending pest management practices that are not adopted by farmers.

Importance of Sorghum and Sorghum Stem Borers

FAO (1986) reports sorghum production from 89 countries, 33 of which are developing countries in the SAT. These countries contribute about 50% of the annual world sorghum grain production of 80 million tonnes, and account for 75% of the 50 million hectare planted with sorghum, worldwide.

In contrast to the sorghum-growing countries in Latin America where sorghum grain is used as animal feed, nearly 90% of sorghum produced in developing countries of the SAT of Asia and Africa is used for food (FAO 1984). Sorghum grain is a staple diet of many subsistence farmers and rural laborers in the SAT, and is an important source of calories and protein. For example, poor rural families in India on average derive 15% of their daily calories and 16% of their daily protein from sorghum (Murty and von Oppen 1985). Detailed surveys in India (Ryan et al. 1984) showed that sorghum contributes about 2/3 of daily protein and calories consumption by rural people in sorghum growing tracts. Sorghum grain is also widely used in the production of indigenous beer in Africa (Haggblade 1987). The uses of sorghum are not confined to grain. Sorghum stalks, for example, became increasingly valuable in parts of India in periods of drought from 1980 to 1986. During that time the price of sorghum fodder rose by about 270%. Fodder's share in the value of sorghum production has increased in the same period from below 50% to more than 70% (Walker 1987). Sorghum stalks are also used for fencing, and provide bedding for livestock.

The severity of damage to sorghum by stem borers varies considerably across regions of the SAT. Harris (1985) estimated overall losses to be on the order of 5-10% in many sorghum-growing areas of West Africa, especially where early attack causes loss of stand. Avoidable grain losses on the hybrid sorghum CSH 1 and the variety Swarna were estimated to be about 55-83% in India (Jotwani et al. 1971, Jotwani 1972). In a survey of cereal losses in Kenya and Tanzania, Walker (1967) reported losses in yield of sorghum due to stem borer damage ranging from 18-27%. A recent survey of farmers' perception of losses due to stem borer in western Kenya reported a range of 15-40% (Seshu Reddy In press). Most losses in yield are attributed to early attack on the growing plant. Correlations of counts of stem damage, with yield at or before harvest, have often failed to demonstrate any reduction in grain yield (Harris 1962, ICRISAT 1987).

Review of Recommendations for Stem Borer Management

Pest management strategies that have been suggested for sorghum stem borers in the SAT (cultural, chemical, and biological control, host-plant resistance, and integrated pest management) are briefly reviewed in this section. The more exotic control methods such as the use of pheromones, juvenile hormones, and chemosterilants are excluded.

Cropping Practices

Cropping practices can be conceived as having evolved over long periods of time and being well-adapted to local environments. Changes in cropping practices can have important impacts on stem borer ecology that may be exploited in pest management. Such changes may, however, have intricate agronomic and economic side effects that are difficult to anticipate and that diminish the acceptance of recommended cropping practices by farmers.

Rotations

Rotations can check stem borer population build-up by removing primary hosts of the pest for extended periods. Rotations including fallow, however, have vanished in parts of the SAT with explosive population growth, increasing land pressure, and declining land productivity (Matlon and Spencer 1984). Furthermore, the arrival or absence of rains, sudden changes in price ratios, and other variables outside the control of farmers often impede the planned succession of crops. For example, analysis of the crop choices of a small sample of farmers in India showed that about half of all attempted rotations are interrupted (ICRISAT 1987).

Intercropping

Most farmers in the SAT grow sorghum in crop mixtures, usually with legumes and sometimes with other cereals. In general, crop mixtures reduce pest incidence when the choice of the crops in the mixture is properly done. However, the individual component crops may not equally benefit. For example, in Kenya, Ogwaro (1983) found increased borer levels in maize when intercropped with sorghum, while borer levels remained the same in sorghum. Amoako-Atta and Omalo (1983) found that a sorghum/maize intercrop was more favorable to *C. partellus* attack than an intercrop of sorghum and cowpea. Similar studies by Mahadevan and Chelliah (1986) in India showed a much higher incidence of borer attack and lower yield in monocrop sorghum compared to sorghum intercropped with lablab *(Lablab purpureus* (L.) Sweet). Although there is scientific evidence of an effect of the composition of sorghum intercrops on stem borer ecology, there are no studies showing that farmers grow specific sorghum intercrops to exploit this effect.

Sowing Date

In the sorghum tracts of the SAT, sowing of sorghum is determined by rainfall. Planting after the first rains is the first step the farmer takes to ensure a good crop. This practice has considerable relevance to stem borers since the early sown crop usually suffers less borer attack than a crop sown later (Harris 1962, Nwanze 1981). Deviations from this rule are usually founded on other constraints that farmers have to consider, such as soil type and topography of plots (Matlon 1980), labor bottlenecks, or risk of crop damage from other insects. Given the many constraints affecting farmers' choice of sowing dates, it is unlikely that a change m sowing dates alone will result in higher sustainable sorghum yields.

Farm Sanitation

Several stem borer species will carryover in sorghum stems (C. *partellus, B. fusca, A. igncfusalis)* or survive the dry season on alternate wild grass hosts *(Sesamia* spp). Collecting and burning stubble and stalks, or plowing and destroying crop residue are recommended practices (Bowden 1956, Nye 1960, and Harris 1962). Adesiyun and Ajayi (1980) found in northern Nigeria that partial burning of stalks killed 95% of diapausing *B. fusca* larvae, and cured the stalks, improving their quality for housing and fencing material. Species that survive on dry season wild graminaceous hosts are effectively controlled by crop removal. In the densely populated SAT areas of India, field sanitation can hardly be improved. Here all plant residue is either grazed or collected by the abundant farm labor. In Africa, where farm labor is scarce and draft animals are not typically used, postharvest plowing is very costly. Sorghum stalks used as fencing material may have no cheap substitutes in remote rural areas or may be too valuable as fodder to be burned.

Manuring

Farm manure provides nutrients, improves soil structure, and increases soil water-holding capacity, which in turn improves plant vigor and growth. Vigorously growing sorghum suffers less borer damage and escapes deadheart formation. Although livestock numbers are increasing at a slow pace in the SAT of India, the ratio of livestock per cropped area is stagnating, limiting the scope for increasing application of manure. Furthermore, where firewood is scarce, dung is also used for fuel. Farming households in India burn about 1 t ofdried dung per year (ICRISAT 1986). These factors cause farmers to apply manure less frequently and in lesser quantities than they would if more manure was available.

Local sorghum cultivars in India rarely receive manure. Walker and Rao (1982) found that only 1.4% of the plots planted with postrainy season local sorghum in two villages of Maharashtra, India, received manure. In contrast, 60% of the high-yielding varieties (HYV) sorghum plots in another village of the same state received inorganic fertilizer. Farmers believe that sorghum is more responsive to inorganic fertilizer than to manure and reserve the available manure far cash crops. Evidence from 56 villages in 10 countries in sub-Saharan Africa indicates that manuring fields is a practice that evolves with increasing farming intensity from fallow to annual cropping systems (Binswanger and Pingali 1984).

Chemical Control

Several insecticides have been tested for the control of stem borers. Their efficacy depends crucially on the timing of application. In Africa, chemical control by carbofuran, carbaryl, and endosulfan were found effective against *B. fusca* and *Sesamia* spp. (Taneja and Leuschner 1985, Seshu Reddy and Omolo 1985). Sharma (1985) listed nine insecticides that are effective against *C. partellus* in India. Granular formulations of carbofuran applied directly into the whorl gave reasonable control against C. *partellus* although the procedure is labor-intensive and was recommended only as a last resort (Teetes et al. 1983). High labor intensity would probably not prevent farmers in India to do this if stem borer were a severe yield reducer. These insecticides are, however, often unavailable in rural areas or too expensive for subsistence farmers. The assessment of chemical control of sorghum in the SAT by Davies (1982, p. 220) is as valid today as it was 6 years ago: "In general, there is little convincing evidence of the economic soundness of some of the recommendations made for insecticide use on sorghum, in developing countries, except in special high input, or at least high fertility ... situations".

Chemical insect pest control on local cultivars of sorghum is conspicuously absent in India. Evidence from three study villages in different agroclimatic zones in SAT India (Binswanger and Ryan 1980) shows that only hybrid sorghum is sometimes treated with insecticides in the event of shootfly or midge attack. We have no reports from our village investigators that farmers actually apply insecticides directly into the whorl.

Biological Control

A number of natural enemies have been reported (Pradhan et al. 1971, FAO 1980, Seshu Reddy and Davies 1979, and Sharma 1985). In general, the efficiency of natural enemies in particular farming environments is not known. The scope for successfully controlling sorghum stem borers with natural enemies is limited by the short cropping period and the lack of continuous habitats for the natural enemies. The introduction and establishment of *Trichogramma exiguem,* a parasitoid on *C. partellus* eggs, represents a notable success in India (Jotwani 1982). In Africa, the overall rate of parasitism is low and only increases when borer damage is well advanced (Harris 1962, Nwanze 1985).

Host-plant Resistance

At ICRISAT Center, more than 70 germplasm sources and breeding lines have been identified as resistant to stem borer *C. partellus.* These materials are currently being used in ICRISAT's breeding programs. Sharma (1985) also listed 34 entries of which 25 were highly promising, having stable resistance and good agronomic characteristics. Several local cultivars and landraces exhibit a high tillering ability, and tillering, as an aspect of varietal tolerance at low borer infestations, may result in an overall increase in head production (Harris 1962). Mechanisms of resistance and further studies on oviposition behavior and crop physiology will provide an adequate foundation for the development of integrated pest management programs. At this time, however, stem borer resistant cultivars have yet to be released in the SAT. Furthermore, germplasm has not been screened for multiple resistance. We cannot, therefore, deny the possibility that cultivars developed from stem borer resistant germplasm might break down when exposed to multiple pest and disease pressure in farmers' fields.

Integrated Pest Management (IPM)

The individual control methods discussed above have their limitations and none is sufficient to adequately control stem borer outbreaks. When no single control option is sufficient, one may try to exploit the interactions of different control strategies integrated in a pest management system. IPM takes into account the interactions between biotic, abiotic, and economic factors of crop production, and pest management itself becomes part of managing or producing a crop. The limitations of individual control methods indicate that host-plant resistance and cultural practices should be major components in the integrated management of sorghum stem borers.

Where integrated pest management has seriously been tried, its transfer to farmers often met with constraints that were not anticipated by entomologists or social scientists. The main deficiency of many IPM recommendations is that they are too complicated to be explained by extension workers and to be adopted by farmers. Adoption of thresholds, a cornerstone of IPM, is an example. Carlson and Mueller (1987) found that adoption of thresholds by pigeonpea growers in SAT India was much slower than adoption of ultra-low volume sprayers and that farmers with little or no formal education are very unlikely to be among the early adopters of thresholds. Drawing on her experiences of IPM field work in the developing countries, Goodell (1984, p. 18) characterized IPM as follows:

"Of the various components of modern agriculture, IPM presents by far the most difficult challenge to traditional, small-scale farmers in the Third World as they make the transition to scientific farming."

Assessment of the Recommendations

Recommendations for stem-borer management, although appearing promising, have not carried far beyond the research stations and libraries. Farm sanitation can either not be improved or only be improved at high cost. Sowing dates are confined by several constraints and are likely to be well-timed in traditional farming systems that have evolved over long periods. Rotations are often obstructed by the vagaries of the weather in the SAT. Manuring local cultivars of sorghum is unattractive to farmers. Sorghum cultivars that are acceptable to farmers and resistant or tolerant to stem borer and other yield reducers are yet to be released. There is no consistency in stem borer control through intercropping, and biological control is inefficient. Integrated stem borer management, finally, is likely to be severely constrained by the limited management capability of farmers. What has prevented stem borer research from contributing more to sorghum improvement? It was certainly not a lack of commitment on the part of researchers, nor were they lacking in competence or devoid of a sense of urgency to solve the stem borer problem. More likely it was the contrary: highly motivated, competent researchers attempted to achieve transferable results quickly, often with frugal financial support, by applying research approaches from mentor institutions in developed countries to the SAT.

Applying methods and principles of entomology in subject matter research on stem borers in the SAT is necessary. Transferring approaches to problem solving stem borer research from developed to developing countries is perilous: it encourages cursory problem identification and acceptance of recommendations without critical appraisal.

Problem-solving stem borer research has to consider that practical problems are location-specific. As mentioned earlier, estimates of yield losses from stem borer attack vary considerably across regions and range from 5-83%. Second, yield losses from stem-borer, as perceived by scientists, may be imperfect indicators of farmers' perceptions of the importance of stem-borer management. Third, solutions of practical problems have to take into account the preferences, skills, resources, and constraints of the people whose problems are to be solved. We do not have to elaborate again here the contrast between farmers and their environments in the SAT and in the developed countries from where research approaches have been borrowed. These differences often prevent solutions from being successfully transferred from developed to developing countries. In short, stem borer research has not been conducted with a farming systems perspective. This defect most likely contributed to the dearth of stem borer management recommendations that can be adopted by farmers.

Stem Borer Management: A Farming Systems Perspective

Elements of Research Conducted

Over the last decade literature on farming systems research has burgeoned and the farming systems approach has been recommended for research on pest management technologies for small-scale farmers (Altieri 1984). The essentials of farming systems research are that it is conducted with a farming systems perspective, that research begins and ends with the farmer (Plucknett et al. 1987). Several of the objectives and methods employed in farming systems research should be considered lor introducing a farming systems perspective into applied stem borer research.

The main objectives of research with a farming systems perspective that are relevant for stem borer management research are:

- to understand the physical, social, economic, and human environment of agricultural production;

- to understand farmers' skills, constraints, preferences, and aspirations;
- to comprehend farming systems;
- to identify possibilities for improving existing farming systems;
- to evaluate new or improved practices for possible testing on farms; and
- to test practices under normal farm conditions.

Research with a farming systems perspective pursues these objectives mainly with three methods: (a) Base-data analysis for describing the farming environment in a region; (b) research station studies for the development of new components or the assembly of new farming systems; and (c) on-farm studies which involve on-farm experimentation studies of existing farming systems, and studies of adoption and farm-household impacts of a new technology.

Objectives and Methods Applied to Stem Borer Research

In Table I we have correlated objectives and methods for stem borer management research conducted with a farming systems perspective. In this section the elements of Table 1 are discussed.

Production Environment. In the past, stem borer research has given adequate attention to the physical environment of sorghum production. We expect researchers will also quickly absorb more detailed information on the climatic and edaphic conditions in the SAT as it becomes available through research reports.

But the economic and political environment of sorghum production in the SAT also requires continuous monitoring by researchers. This is particularly true in Africa, where some governments have not yet attained levels of stability found in many Asian countries, and where agricultural research and extension systems often are less developed. We do not suggest that entomologists engage in detailed surveys of the economic, political, and infrastructural environment of agricultural production, because much of the necessary information is provided by social scientists and by the local press. We do recommend, however, that sorghum entomologists consult social scientists and watch key price ratios that indicate changes in the economic environment. Some of the key indicators are the price ratios between the farm-gate sorghum price and rural labor wage rates, or the prices for other food staples, or the prices for insecticides.

Table 1. Objectives and methods of stem borer management research conducted with a farming systems perspective.

	Methods			
		ExperSiments		
Objectives	Surveys	On-farm	On-station	Modeling
Environment	**			
Farming System	**	**		
Farmer	**	**		
improve technology		**	**	
Evaluate new technology			**	**
Test new technology	**	**		

Farming System. An understanding of the farming system, not just the cropping system, is particularly important for stem borer researchers in the SAT. There are many intricate linkages between the various production and consumption activities of small substistence or semi-subsistence farmers, and farmers may attribute little importance to stem borers as yield reducers. If stem borer management options are to be adopted by farmers they must fit into existing farming systems. Rarely are stem borer losses sufficiently high that farmers are likely to change their farming system only to accommodate a stem borer management recommendations.

Farmers. At the outset of any applied, problem-solving stem borer management research, entomologists should provide evidence on whether the insect is merely a pest or a pest problem for farmers. This distinction between pests and pest problems is important. Stem borers are regarded as pests because they cause economic damage to sorghum. This is necessary but not a sufficient condition for stem borers to become a pest problem for farmers. Several other conditions must also hold before stem borers can be regarded as a pest problem.

First ot all, farmers must be able to associate the pest with economic damage. This ability is likely to be conditioned by farmers' knowledge and skills, the degree of their exposure to farm management information from extension services and other farmers, and the attention they give to sorghum.

Second, farmers may not regard stem borers as a problem pest when the perceived losses are small in relation to the perceived losses caused by other biotic and abiotic yield reducers of sorghum, or where sorghum contributes little to the subsistence of the farm families. Under such conditions, stem borers are unlikely to attract the scarce management attention of farmers.

Third, stem borers are not a pest problem unless farmers have at their disposal means for reducing economic losses. Without a feasible pest management option, farmers may regard stem borers as a pest but not as a pest problem.

Establishing that stem borers are a pest problem for farmers requires that surveys of stem borer damage in farmers' fields are complemented by surveys of farmers' perceptions of stem borers as a pest. Such surveys do not have to be large exercises involving entomologists, agronomists, and social scientists equipped with a detailed questionnaire. Often an exploratory survey using rapid rural appraisal techniques may be sufficient to pesuade the researchers that stem borers are not a burning problem for farmers in whose fields entomologists have detected deadhearts and stem tunneling. Where more substantial evidence is required, a formal questionnaire survey may be needed. Guidelines for formal perception surveys can be obtained from a pest perception network operating from the Open University, UK (Tait 1981). Whether a recommendation is a solution for a farmer's stem-borer problem depends on the skills of the farmer and the farm's labor force, on the costs of implementing the recommendation, and on the expected returns from stem-borer management. The adequacy of farmers' and laborers' skills for implementing a recommended control practice can be assessed from experiences with similar practices but can be determined only in on-farm trials. Assessment of the costs of a stem-borer management option has to be based on the farm-gate prices of purchased inputs, and the value of the farm-owned resources in their best alternative use at the time when they are needed for stem-borer control. The value to farmers of their owned resources may deviate considerably from average market prices, are usually location-specific, and may fluctuate considerably during the cropping season.

Assessment of the expected returns has to be based on farmgate prices for sorghum at the time it is sold. This assessment must take into account that sorghum stems are a valuable commodity, and should consider the effect of stem-borer management on the farmers' production and marketing risks. Methods for assessing the costs and returns of pest management options are well established and an excellent exposition was provided by Reichelderfer et al. (1984). In many instances the required methods do not require an economist.

Improve Technology. Sometimes there may be an opportunity for improving farmers' pest management practices with adaptive on-farm research. Several researchers have invested much hope in this approach (Matteson et al. 1984). From our experience in India, we are skeptical about this approach because we have so far been unable to identify traditional methods used by farmers to manage sorghum insect pests that have a potential for improvement through research (Rao and Mueller 1986).

Evaluate New Technology. Evaluating new technologies in on-station experiments is the mainstay of traditional pest management research. Adoption of a farming systems perspective would not require substantial changes in the experimental methods. It would, however, require a broader set of criteria for evaluating the results from experiments, and appropriate selection of controls. Conventional research uses classical statistical hypothesis testing to decide whether a new management technique performs in some variable(s) better than a control technique with some arbitrary level of significance. Such research may be irrelevant from a farming systems perspective. Classical statistical techniques are designed to rule out Type I errors, the error of rejecting the null hypothesis when it is true, or the error of recommending a technology that is not superior to the control. The conventionally chosen probability of committing this error bears no relation to the economic consequences of this error. The farming systems perspective could be introduced into the analysis of experiments with neo-classical statistical methods that take the costs of selecting a nonsuperior technology into account (Manderscheid 1965, Dillon and Officer 1971).

Technology evaluation, the evaluation of new cultivars in particular, is often conducted according to rigid rules defined by a large government research administration. These rules are designed to select the best technologies for a country, or for large agroclimatic zones, but may be too rigid for location-specific technologies that perform very well in some locations, but poorly in the larger environments covered by these evaluation rules.

With the rapidly falling costs of computer time, modeling is becoming an increasingly attractive opportunity for introducing a farming systems perspective into the evaluation of new technologies before they are actually tested on farms. However, computer models usually have high set-up costs and their use can be recommended only when the prospective technology will have many important and complex repercussions in the existing farming systems.

Testing New Technology. Once a promising new stem borer management option has been identified in on-station experiments, it should be tested on a small number of representative farms before it is recommended to a large number of farmers. These tests should be designed to evaluate the feasibility and the performance of the new option compared with farmers' conventional techniques. These tests also help to identify weaknesses or defects of the technique that may have gone unnoticed in on-station experiments. They provide feedback from farmers that is essential for fine-tuning the recommendation.

The most crucial test of any new technology is its adoption by farmers. The recommendation of a new pest management technology should be followed by adoption studies that include adopters as well as nonadopters. Such studies rely on surveys. They allow researchers to document the success of their research, they provide information on the characteristics of researchers' clients and their assessment of the new methods. This information helps researchers to design the next generation of technology, and to obtain funds for its development.

Summary and Conclusions

In this paper we have briefly reviewed the practicality, and adoption, of stem-borer management recommendations that have been reported in the literature. This review indicated that most recommendations are impractical and have not been adopted by farmers in the SAT. The introduction of a farming systems perspective to applied stem-borer management research was suggested and some appropriate objectives and research methods were discussed. Our expressed concern was for applied stem-borer research to take into account farmers' perception of the stem-borer pest problem and farmers' capacity to implement recommended stem borer management practices so that applied research results in recommendations of practical use to SAT farmers. This notion has been aptly summarized by Reichelderfer and Bottrell (1985, p.286): "Identification of the basic needs and objectives of a technology's recipient group is obviously an important step, but one that is not always performed. Bypassing this step will probably lead to poorly designed pest-management programmes."

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Discussion

Reyes: Since older plants (six weeks old) are preferred for oviposition, is this related to the nutritional status of the plant on which the larvae will feed?

Harris: Possibly, but I do not have relevant information. Borers on crop hosts seem to have developed the strategy of going for the youngest tissues. Evidence of recent work on *Chilo* in Africa suggests that leaf whorl tissue is more nutritious.

Nwanze: You spoke on the co-evolution of cereals and their stem borers. We know that sorghum and pearl millet originated in Africa and that the important stem borers are indigenous to Africa. One would have expected that the natural enemies of stem borers would have also evolved in parallel with their hosts, but this is not the case. Could you please elucidate?

Harris: This is a relevant question and it is a huge topic. It is a matter of balance; part of the answer is that the natural enemies are not operating the strategy that you would like them to operate. Furthermore, the strategy of natural enemies is not aimed at eliminating their hosts. Many are general parasitoids or predators developing on a wide range of hosts. What we have are specialist stem borers that we would like best controlled by highly specialized parasitoids. Not that many exist.

Vidyabhushnam: It was suggested that chemical control measures should be adopted whenever necessary. How do you ascertain which situation warrants the use of chemical control? Furthermore, would it be valid in the case of peduncle infestation?

Prem Kishore: The reference to chemical control was in the context of determining economic thresholds. Studies on insecticide application to protect against peduncle infestation are still lacking. This needs to be investigated.

Sharma: If I have understood correctly, you have mentioned that carbofuran provides borer control for up to 45 days. In that case, would you recommend any insecticide control since at that stage the crop will be in the boot leaf stage?

Prem Kishore: Data from trials conducted on seed treatment, soil furrow application, or side-dressing at 15 days after germinaton indicate that under moderate levels of resistance there is no need for another application of carbofuran.

Suryanarayana Murthy: What are the effects of insecticides used in borer control on the natural enemy complex? What are the dangers of borer resistance to insecticides as we now have in *Heliothis?*

Prem Kishore: The effect of different insecticides used in sorghum stem borer control on natural enemies has not been studied in detail. However, data generated on the effect of endosulfan 4% granules or dust show that its application does not affect natural enemies. *C. partellus has* not developed resistance to insecticides.

Vidyabhushnam: Delayed planting has been suggested in cultural control of stem borers. But this practice would be disastrous in the Indian context, where shoot fly infestation would surely wipe out a late crop. Moreover, a fortnight's delay in planting will seriously affect the crop expression. Is this recommendation therefore of any practical value?

Varma: The suggestion in question is not a generalization for saving the crop against stem borer. It is pertinent, however, in regions where shoot fly is not a problem. For example, in northern India where sorghum is grown for fodder, we sow in July.

Lukefahr: Do you know of an example where the combined action of the native parasites actually suppressed borer population below the economic threshold level?

Betbeder-Matibet: A good example is in West Africa with the sugarcane stem borer, *Eldana saccharine.* The natural enemy complex of ants, parasites, and predators have kept borer damage to less than 5%. We have monitored this borer for more than 10 years in several sugarcane farms and have found this level maintained. When this balance is upset, for example, through the use of insecticides, borer damage on stems increases to between 15 and 20%.

Seshu Reddy: In assessing yield loss using various larval densities at various growth stages, what precautions did you take to eliminate natural infestation?

Taneja: In trials conducted at ICRISAT Center, crops were planted in mid-June when natural infestation is negligible. Any natural infestation is taken into consideration by comparison with the control (zero infestation). Usually this is less than 1% infestation.

Seshu Reddy: In your studies on avoidable losses you certainly encountered other sorghum pests such as midge and headbugs. What steps did you take to protect your crop against these insects so as to have accurate data on losses due to stem borer?

Taneja: We spray to protect the crop from possible panicle feeding pests, as and when required. Similarly, we use bird scarers against birds.

Chundurwar: You have presented the results of your studies with particular hybrids such as CSH 1. but we need to have results on the released hybrids in India, especially CSH 5 and CSH 9 for comparison.

Taneja: We do not have such results and similar trials with CSH 5 and CSH 9 need to be conducted.

Nwanze: Dr Leuschner has pointed out that the effect of stem tunneling on grain yield depends on crop age at infestation and point of borer entry and attack. However, there are no data to show this. 1 believe that with the stem cage technique, we should conclusively show that this is the case. Experiments should be designed in this regard.

Wiseman: This should be a major point for discussion by Dr Verma's group.

Lukefahr: Based on data provided by Dr Taneja, one needs to have infestation early in the season with a level of infestation that greatly exceeds what one normally expects in the first or second generation. I am wondering if there really is a problem in farmers' fields.

Mueller: There may be a problem in farmers' fields but from our observations, farmers are not particularly concerned with stem borers. Farmers may have 5-10% losses due to borers, but they may have bigger problems such as drought and *Striga* that dwarf losses due to borers.

Nwanze: There are practically no data available from farmers' fields on actual losses due to borers. There are, however, reports on pest incidence. Our definition of a pest is often based on research station findings. We need data that show its magnitude on farmers'fields. We also need to take farmers' perception of the problem into consideration.

Lukefahr: We should be careful, because otherwise you set up a research program to see if a problem exists rather than to solve a problem.

Nwanze: But that is where the problem lies. It is wrong to set up a research program based on information generated solely from a research station. We must accumulate base line information on the extent of damage on farmers' fields.

Leuschner: How would your decision, in terms of research priorities on stem borer control, be affected in a situation where farmers perceive 15% damage by stem borer as unimportant?

Mueller: What is important is farmers' perception of stem borer damage relative to losses from other yield reducers. For example, if the same farmers perceive losses from other yield reducers such as *Striga* to be much higher than 15%, and if this perception is supported by yield loss surveys, stem borers would not be listed as top priority for applied, problem-solving research.

Seshu Reddy: We cannot solve all the problems in one day. There are several constraints besides insect pests which the farmers must deal with. We need to support our on-station research with what is really happening on the farmers' field.

Harris: There are all sorts of technicalities, and technical aspects to the issue of whether stem borers are a problem or not. We, as entomologists, may see this as a problem but I think in many cases farmers do not. There must be situations when they do, and those are the situations that have to be defined so that something practical can be done in providing solutions. These are some of the key issues being considered in this workshop. If there are problems, where are they, and what do they amount to? The first thing to do is to try and assess the losses, if they occur. It is not easy, but it is the first step in setting up proper research programs which are intended to provide applied solutions.

Host-plant Resistance

Methodologies Used for Screening for Resistance to Fall Armyworm in Sorghum

B.R. Wiseman[1]

Abstract

Methodologies used for screening for resistance in sorghum, Sorghum bicolor *to fall army worm* Spodoptera frugiperda *are reported. Screening for seedling and whorl-stage resistance is accomplished by applying neonate fall armyworm mixed in corncob grits with a mechanical infestation device at the rate of four larvae per 2-day old seedling. For seedlings, visual ratings of leaf-feeding damage are made on a scale of 0-9 when the susceptible control seedling approaches a rating of 9; for whorl-stage plants, visual ratings are made 10 and 14 days after infestation. Evaluations of panicle-stage resistance may be made directly in the field under artificial infestation or in the laboratory using a meridic-based diet bioassay. Resistance in the seedling and whorl stage of leaf development has been located in 1821 cm and at the panicle stage in NK-Savanna 5.*

Résumé

Méthodes utilisées pour les tests de résistance du sorgho à* Spodoptera frugiperda *: *Les méthodes utilisées pour les tests de résistance du sorgho (*Sorghum bicolor*) à* Spodoptera frugiperda *sont décrites. Le criblage pour la résistance aux stade plantule et "feuilles enroulées" est effectué en déposant, à l'aide d'un dispositif mécanique, des larves néonates mélangées avec du gruau de maïs à raison de quatre larves par plantule de deux jours. Pour les plantules, les dégâts foliaires visibles sont notés selon une échelle allant de 0 à 9 lorsque les dégâts sur la plantule témoin sensible atteignent le niveau 9; pour les plantes au stade "feuilles enroulées", les dégâts sont notés 10 à 14 jours après l'infestation. L'évaluation de la résistance au stade paniculaire est faite, soit directement au champ sous infestation artificielle soit au laboratoire dans un bioessai avec un milieu nutritif meridique. L'entrée 1821 cm a montré une résistance aux stades plantule et "feuilles enroulées" et NK-Savanna 5 au stade paniculaire.*

Introduction

A thorough understanding of the insect and plant relationship is required before a program of plant resistance is initiated. Techniques for measuring differences in damage to cultivars is probably the key factor in determining the success or failure of any program for developing insect resistance (Dahms 1972). Little comprehensive information is available on techniques to infest and evaluate for insect resistance; such information is especially lacking on sorghum, *Sorghum* bicolor (L.) Moench. However, recently, Heinrichs et al. (1985) published an extensive volume of techniques on 24 insect species attacking rice, *Oryza sativa.* Their work reported on rearing, greenhouse and field screening, mechanism of resistance, and sources of resistance. More recently, the maize, *Zea mays,* program at the International Maize and Wheat Improvement Center sponsored a comprehensive symposium directed entirely to methodology used to determine resistance in maize to insects. The published proceedings will cover tech-

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nological subjects such as rearing, infesting, and evaluating, mechanisms of resistance, breeding, and the use of the resistant cultivars in management of pests. All maize insects are presented.

Even though extensive and comprehensive technological advances have been made for some crops and insect species, the techniques usually cannot be completely adapted to new insects or crops without extensive modifications. But the ideas and applications that have been reported can be readily used to develop new techniques for each insect pest under investigation.

Fall Armyworm

More than 190 years have passed since the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), was first recognized as a serious economic pest (Luginbill 1928). It is one of only a few insects that periodically disperse and breed throughout the U.S. The FAW plagues many food crops and grasses and can limit production of many crops in various areas of the southeastern U.S., Mexico, and Central and South America (Wiseman and Davis 1979).

Entomologists will remember 1975, 1976, and 1977 as years of heavy FAW infestations throughout the southeastern U.S. Estimated dollar losses attributed to FAW on all crops in the southeastern U.S. in 1975 were $61.2 million and in 1976, $31.9 million, and the 1977 losses in Georgia alone were estimated at $137.5 million (Sparks 1979). One of the most important pests of sorghum in recent years in the southeastern U.S. and in much of Central and South America has been the FAW.

The adult of the FAW is nocturnal. At dusk, adults initiate movement toward host plants that are suitable for feeding and oviposition. Eggs are laid in clusters and protected by a dense covering of scales. Masses contain from a few to hundreds of eggs. which hatch in 2-4 days if mean temperatures are 21.1-26.7°C. As the eggs hatch, the larvae consume the shells and then initiate feeding on the plants until they have completed six instars (Luginbill 1928, Sparks 1979). The sixth instar drops to the ground and pupates in the soil at a depth of about 2.54-7.62 cm, depending on soil texture, moisture, and temperature; the life cycle requires about 30 days.

In sorghum, it is necessary to recognize the different instars that cause injury to the plant and the plant stage attacked. Also, it is important to determine whether damage was caused by the FAW or by similar pest species. Mixtures of larvae such as the corn earworm (CEW) *Heliothis zea* (Boddie), and FAW cannot be studied together unless a determination is made that both species have identical preferences and that the resistances expressed are identical. This is very doubtful since these insect species are quite different—both in behavior and in host-plant preference. Thus, evaluations for resistance in sorghum must be such that the two insect pests are separated by time and/or space. This can be accomplished when the test insects are mass-reared.

Insect Rearing

The plant resistance program has been greatly enhanced by artificial rearing of the FAW. FAW are mass-reared on a modified pinto bean diet (Table 1) (Burton 1969, Perkins 1979). The modified pinto bean diet is used because the wheatgerm-casein diet is more expensive and the wheat-soy-blend (WSB) (Burton and Perkins 1972) is no longer commercially available (Burton and Perkins In press).

Table 1. Ingredients for the fall armyworm diet and sources of diet ingredients[1].

Ingredient	g L^{-1} of diet	mL L^{-1} of diet
Pinto beans[2]	120.0 (dry)	
Torula yeast[3]	35.0	
Ascorbic acid[4]	3.5	
Wheat germ[5]	55.0	
Methyl p-hydroxy benzoate[6]	2.2	
Sorbic acid[7]	1.1	
Formaldehyde (10%)[8]		10.0
Water (for mixing above ingredients)		465.0
Agar[9]		15.0
Water (for agar solution)		360.0

1. Institutional Wholesale, Inc., P.O. Box 4747, Macon GA 31208.
2. Lake States Division, Rhinelander Paper Co., Rhinelander, WI 54501.
3. Hoffman LaRoche, Inc., 340 Kingsland Rd.,Nutley,NJ 07110.
4. Vitamins, Inc., 200 East Randolph Dr.. Chicago, IL 60601.
5. Kalana Chemical, Inc., 290 River Dr. Garfield, NJ 07026.
6. 1CN Pharmaceuticals, 26201 Miles Rd.. Cleveland. OH 44128.
7. Fisher Scientific. P.O. Box 4829, Norcross, GA 30091.
8. Perny, Inc., P.O. Box 711, Ridgewood, NJ 97431.
9. From Burton and Perkins (in press).

Mention of a commercial product does not imply endorsement by USDA.

Estimated costs for rearing 1000 FAW in 1987 was about $16.00, exclusive of labor. The FAW has been reared for more than 20 years on the artificial diet through 300 or more generations. Plans are afoot to introduce wild males into the laboratory culture at least once a year to prevent inbreeding and to keep the laboratory insects as near to the feral population as possible. For details of the day-to-day procedures and techniques for rearing the FAW, refer to Burton and Perkins (In press).

Plant Resistance

Grain sorghum is one of the most important food and feed grain crops in the world. Luginbill (1969) stated that "the ideal method of combating insects that attack plants is to grow insect-resistant cultivars". The development and use of plants resistant to pests is essential to most integrated control programs. In fact, Wiseman (1987) showed that the resistant cultivar should be the base from which integrated pest management strategies arise.

Plant resistance can be defined as "the relative amount of heritable qualities possessed by the plant which influences the ultimate degree of damage done by the insect in the field" (Painter 1951). This definition applies today as it did more than 30 years ago.

Painter (1951, 1968) classified plant resistance into three mechanisms: nonpreference, antibiosis, and tolerance. Nonpreference results when a plant or cultivar is used less for oviposition, food, and/or shelter. A nonpreferred plant may possess combinations and/or levels of these nonpreferred qualities. Nonpreference may be further classed as relative or absolute (Owens 1975). Relative nonpreference denotes that the pest insect has a multiple choice, and absolute indicates that the insect has only one choice to oviposit, establish, or feed on a particular plant or cultivar. Absolute nonpreference is the stronger of the two. Antibiosis relates to the adverse effects (e.g., mortality of larvae, smaller insects, longer development time, etc.) on the insect which uses a resistant plant for food. Again, there may be combinations and/or levels of these types of antibiosis within the same plant or cultivar. Lastly, tolerance describes a plant or cultivar that is able to produce well despite infestations that seriously damage susceptible plants. Tolerant plants may grow and reproduce, repair injury or compensate, or recover from damage to a marked degree in spite of supporting an insect population that damages a susceptible plant or cultivar (Painter 1951, Painter 1968). Combinations and/or levels of the three mechanisms of resistance may be present in a plant or cultivar to confer a given degree or level of resistance.

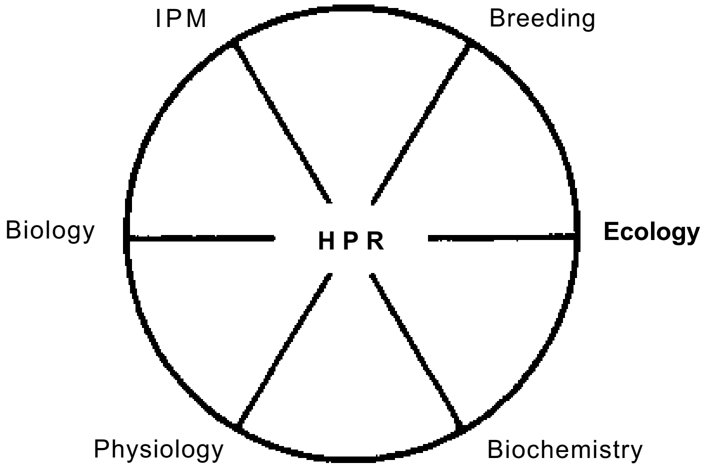

Figure 1. Key areas in which methodology should be developed for a successful plant resistance program.

Knowledge of prior research, and the biological developments of the sorghum plant and FAW relationship, should precede any new plant resistance investigation. As shown in Figure 1 (Wiseman 1985 and In press), methodology must be developed in several key areas before significant progress can be made in the development of sorghum plants resistant to FAW.

Dependable and repeatable techniques must be developed for any phase of a plant resistance program to make regular progress (Wiseman et al. 1980a). The techniques must be as simple as possible and must be efficient and accurate (Guthrie 1975). The methods that are developed should produce maximum difference between the resistant and susceptible cultivars (Wiseman et al. 1980b). In addition, in order to separate the three mechanisms of resistance and/or various types of resistance within each mechanism, separate and unique techniques must be developed.

Resistance Evaluations

Greenhouse Screening

Sorghum cultivars were planted (26 per metal greenhouse flat) in fine-washed river sand, in rows 40 cm long and 2.5 cm apart, for seedling evaluations

(20-25 seedlings per entry). We now use a large metal flat (187.5 cm x 90 cm x 10 cm deep) that accommodates 250 entries per tray. Outside rows are bordered with a common commercial hybrid. When the seedlings are about 2 days old, infestations are made with neonate FAW by using the modified "bazooka" (Wiseman et al. 1980a). For these infestations, large numbers of FAW eggs, laid on paper towels, are obtained from the rearing section of the laboratory and incubated at about 27° C until they hatch. Larvae are kept in darkness to prevent webbing. The larvae are gently shaken from the paper towels, mixed with corncob grits and precalibrated to a mixture of about 20 ± 2 neonates per delivery through the bazooka. The neonates are dispensed directly onto the sand adjacent to the treatment rows at a rate of 4 larvae $plant^{-1}$ (Fig.2). Both a resistant and susceptible control should be provided when possible. Greenhouse temperatures should be maintained between 27-30° C. Care should be taken when watering the plants daily to direct the water between the rows and into the alleys to prevent disturbing the feeding of the larvae. All entries are visually rated for damage when the susceptible control reaches 9, its maximum damage rating. Usually this occurs about the fourth day after infestation. Additional ratings on succeeding days may be taken to detect if any entries are more resistant than the resistant control.

A visual plot rating scale of 0-9 is used, where: 0=no damage; 1=small amount of pinhole-type injury; 2=several pinholes; 3=small amount of shot-hole type injury with 1 or 2 lesions; 4=several shot-hole type injuries and a few lesions; 5=several lesions; 6 = several lesions, shot hole injury and portions eaten away; 7 = several lesions and portions eaten away and areas dying; 8 = several portions of the whorl eaten away and areas dying; and 9 = the whorl completely eaten away and more areas dying or plant dead (Wiseman et al. 1966). If more than one rating is recorded, then the ratings may be aver-

Figure 2. Infesting sorghum seedlings with FAW neonates mixed in corncob grits using the "bazooka" (Wiseman and Courley 1982).

aged, an analysis of variance calculated, and entry means separated by Waller-Duncan multiple range test. About 16000 exotic sorghum cultivars from Ethiopia and Yemen have been evaluated to date for seedling resistance. Approximately 100 rated better than the resistant control.

Field Screening—Whorl Stage

Tests are usually planted in the field in a randomized complete block design with 3 or 4 replications in rows about 3 m in length and 75 cm apart. Field infestations are made with 20 neonate FAW larvae per plant, at about the 8-10 leaf stage of development, in two applications using a mechanical infestation device (Fig.3). Larvae are obtained in a similar manner as that of the greenhouse screening, and neonates are dropped directly into the whorl. The second application should be made no later than 24 h after the first to prevent larval competition. Visual damage ratings should be made at 10 and 14 days after infesting, using the visual rating scale described above. The damage rating may be a plot rating or ratings of 10 individual plants per plot. The earlier rating permits the researcher to obtain differences in damage by FAW before larval migration is initiated. The visual rating at about 10 days can be made using the scale for leaf-feeding resistance as described by Guthrie et al. (1960).

Panicle Stage

Neonate FAW larvae mixed in corncob grits may be infested directly into the developing panicle at the preflower stage to evaluate for resistance in the panicle stage of development (Fig.4). Larvae are dispensed at the rate of about 50 larvae per panicle in two applications made the same day. Two applications are made to reduce the number of escapes. Usually, 10 or 15 panicles per plot are infested. Paper pollinating bags are used to cover the heads to protect the larvae from contamination by other insect species such as the CEW, and to prevent adverse environmental effects reducing the infestation. Since visual ratings are difficult to estimate, a paired uninfested row is used for comparison when yield is recorded.

Plot means are used in the analysis of variance, and Waller-Duncan's multiple range test is applied to separate mean damage ratings and/or mean yields for the entries.

Laboratory Screening and Mechanisms of Resistance

In order to be completely sure that resistance to FAW could be separated from that of the CEW during resistance evaluations, we had to develop laboratory procedures that would ensure the necessary isolation of the two pests (Wiseman et al. 1984). Since FAW are mass-reared on meridic diets, an ample supply of diet materials and insects is available for laboratory use. The pinto bean diet (Table 1) is used as a base diet in the development of a laboratory bioassay that incorporated fresh or dried plant materials for subsequent feeding to neonate FAW. Diet preparation for the bioassay is as follows:

1. Pinto bean diet may be requested in bulk from the rearing section of the laboratory or made up in 3.85 L amounts.
2. Plant materials may be processed fresh, freeze-dried, or oven-dried (41°C).
3. If fresh plant materials are used, they must be blended in a sufficent quantity of distilled water, i.e., 120mL of water and 50-60 g of plant material, to mix with 300 mL of bean diet. For ease in handling, dry plant materials should be used. About 20 g of dry plant material is blended into 250 mL of pinto bean diet that has been diluted with 150 mL of distilled water. These ratios of materials will result in a mixture that can be readily dispensed.
4. The diet-plant material mixture is dispensed into thirty-six 30 mL (1 oz) or 15 mL (5/8 oz) plastic cups in amounts of about 10 mL per cup, and permitted to solidify for about 2 h.
5. One neonate FAW is placed into each cup after which the cup is capped.
6. The treatment cups are numbered and arranged according to the design of the experiment. The experiments are maintained in a constant temperature room at 26.7 ± 2°C and 75 ± 5% RH and 14 h light.
7. Individual weights of larvae at 8-10 days after infestation are recorded by using an electronic balance interfaced with a recording calculator. Days to pupation and weights of pupae, as well as days to adult eclosion, may also be recorded from the same experiment.
8. A microtechnique is employed when much smaller amounts of plant materials must be used. Sixty mL of diluted pinto bean diet (800 mL diet:200 mL distilled water) is blended in a microblender with up to 2-3 g of dry plant materials. If plant fractions are used, then the

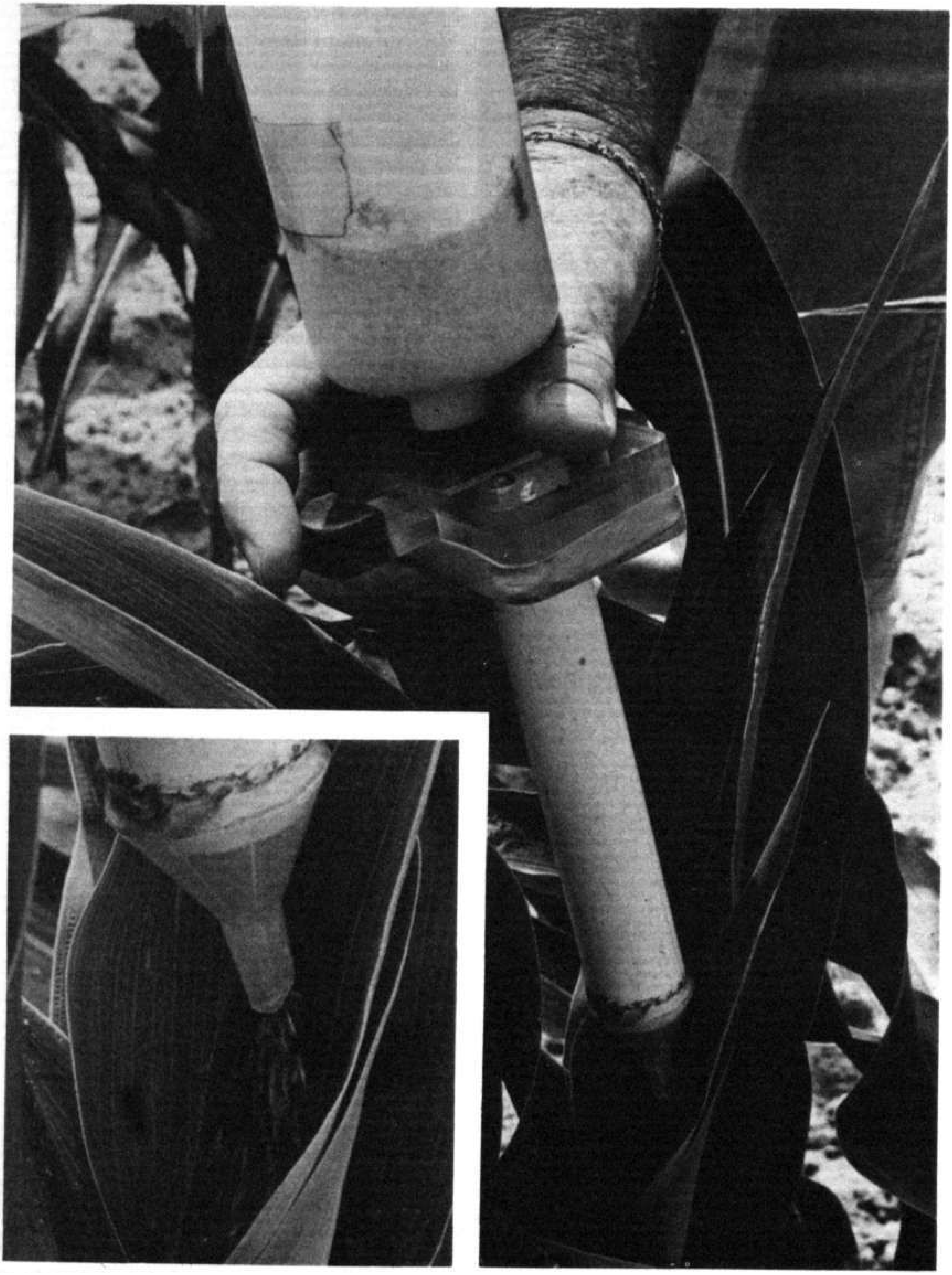

Figure 3. Infesting sorghum at whorl-stage with FAW neonates mixed in corncob grits using the "bazooka"

solvent and extract must be mixed with about 0.5 g of alphacel. The solvent must be evaporated thoroughly and a solvent check, as well as an alphacel check, provided.

9. The blended mixture is aspirated into about seven plastic soda straws, 0.625 cm diameter by 20 cm length, allowed to solidify and sectioned into 20 mm lengths with each end beveled at about 45° angle to permit easy access to the larvae.
10. Two soda straw sections are placed into a 15 mL plastic diet cup with one neonate FAW and capped with a polycoated lid to prevent moisture loss from the diet (Fig.5).
11. The experiments consist of two cups per replicate with 18 replications. The rationale of 18 replications is that the trays hold 36 cups. The analysis of the data uses plot means and is dictated by the design of the individual experiments.

Panicle spikelets of developing sorghum mixed with pinto bean diets and fed to neonate FAW resulted in differences between weights of larvae at 8 days fed 'NK Savanna 5' (resistant) and 'Funk H-5245' (susceptible)(Table 2). Differences in weights of larvae fed the two sorghum hybrids were found at the preflowering, flowering, milk, and hard-dough stages of panicle development. No significant relationship was found between tannin concentration of various stages of panicle development, milk-stage panicles of 12 sorghum genotypes, and weights of FAW larvae. Different types of antibiosis resistance were identified by small larvae, delayed pupation, and small pupae. It was found that the glumes (Table 3) of the sorghum panicles confer the highest level of resistance. The next steps are to begin cooperative work with a biochemist and initiate a chemical fractionation of the plant part(s) and then use the bioassay to direct us to the desired end product.

Figure 4. Infesting sorghum panicle with FAW neonates mixed in corncob grits using the "bazooka"

Summary

The FAW can be mass-reared for sorghum resistance evaluations. Methodologies for evaluating sor ghum for resistance to FAW have been developed. Screening for seedling and whorl-stage resistance of sorghum to FAW is accomplished by applying neonates mixed with corncob grits through the "bazooka" at the rate of four larvae per 2-day-old seedling, and 20 larvae in two applications at the 8-10 leaf stage. Visual ratings of leaf-feeding damage are made on a scale of 0-9 when the susceptible seedling control

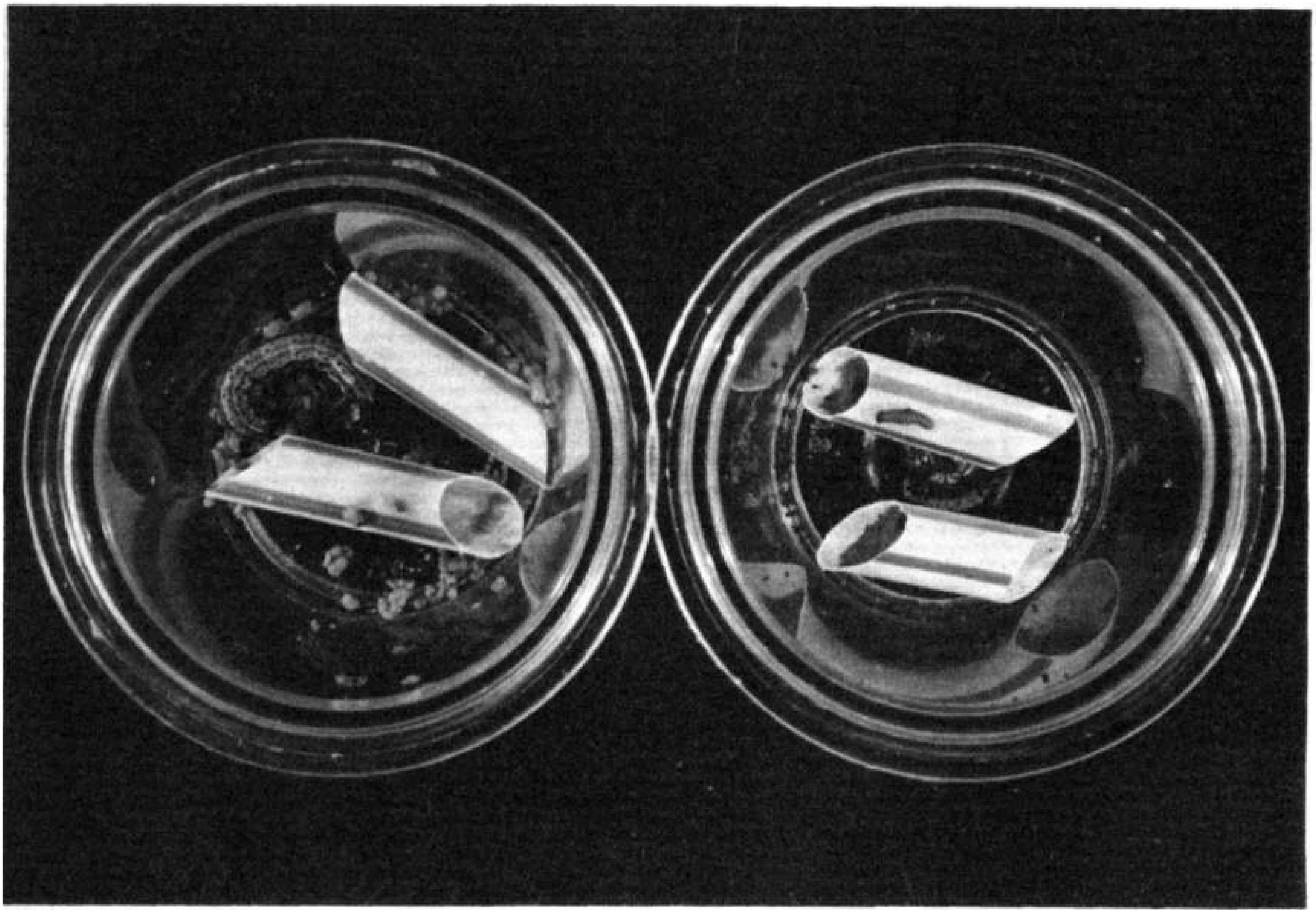

Figure 5. An example of microbioassay to determine differences among entries and/or plant fractions.

Table 2. Weights of FAW larvae after feeding for 8 days on meridic diet supplemented with panicles of two sorghum hybrids and corresponding tannin contents, 1984.

Stage of panicle development	% tannin[1]		X larval wt (mg)[2]		X duration of development (days)[2]		X pupal wt. (mg)[2]	
	Funk H-5245	NK SAV.5	Funk H-5245	NK SAV.5	Funk H-5245	NK SAV.5	Funk H-5245	NK SAV.5
Control diet	-	-	254a	269a	14.8a	14.8a	271a	273a
Preflowering	3.9	7.7	178c	* 214b	14.8a	14.7a	262a	270a
Flowering	1.0	4.7	200bc	* 223b	15.0a	15.0a	277a	274a
Milk stage	0.5	4.9	208 b	* 95c	15.2a	17.8b	274a	* 177b
Hard dough stage	0.3	7.5	259a	* 35d	15.4a	23.1c	207b	* 128c

1. Tannin determined on a dry-weight basis.
2. Means within each column followed by the same letter or means not separated by * are not significantly different [*P* >0.05; Duncan's (1955) multiple range test].

Source: Wiseman et al. 1986.

Table 3. Weights of FAW larvae after feeding for 8 days on merdic diets containing seed, seed and glumes, or glumes of three sorghum genotypes, 1984.

	X larval mass (mg)[1]		
Sorghum genotypes	Seed only	Seed and glumes	Glumes only
Control diet	201.8a A	181.9a A	183.7aA
(Huerin x PI383856) x Huerin	130.9bA	146.IbA	23.96B
TAM2566 x PI383856	108.8cA	81.3cB	6.2cC
SGIRL-MR-2 (selection)	131.8bA	21.0dB	3.4cB
$\bar{X}$	143.3A	107.6B	54.3C

1. Entry means within a column followed by the same lower case letter, and horizontal seed means followed by the same upper-case letter, are not significantly different [P >0.05; Duncan's (1955) multiple range test].

Source: Wiseman et al. 1986.

approaches a rating of 9, and at 10- and 14-days after infestation for whorl-stage sorghum. Evaluations for resistance of panicle-stage sorghum can be made directly in the field under artificial infestation or in the laboratory using a meridic-based diet bioassay. Resistance in the seedling and whorl stage of leaf development has been identified in 1820 cm and at the panicle stage of development in 'NK-Savanna 5'.

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A Review of Sorghum Stem Borer Screening Procedures

K.Leuschner[1]

Abstract

The stem borer screening procedure developed at ICRISAT Center was evaluated for the stem borer (Chilo partellus) *infestation pattern in southern Africa. It was found that the existing screening procedure developed at ICRISAT is biased towards an emphasis on deadheart formation and harvestable main heads, not taking into account tolerance as a resistance mechanism. Therefore, the need arose to develop a modified screening system. In order to understand this, an account is given on the host-plant insect interaction leading to various damage symptoms. The value of each damage symptom for the modified evaluation system is discussed and finally the new screening system is presented.*

Résumé

Synthèse des méthodes de criblage des sorghos pour la résistance aux foreurs des tiges : La méthode de criblage pour la résistance aux foreurs des tiges mise au point à l'ICRISAT a été testée pour le foreur* Chilo partellus *en Afrique australe. Les résultats ont révélé que ce processus privilégie les critères d'apparition de coeurs morts et de nombre de panicules récoltables sans considérer la tolérance en tant que mécanisme de résistance. Il fallait alors modifier le procédé de criblage. Afin d'expliquer cette démarche, l'interaction entre les insectes et les plantes hôtes est examinée dans la mesure où elle entraîne une diversité de symptômes chez les plantes. L'importance de chaque type de dégât est étudiée et en conclusion, un nouveau système de criblage est présenté.

Introduction

For any host plant resistance program it is essential to develop a screening procedure based on insect-host interactions. Plant resistance to insects considers both the reaction of the host to insect activity and pest population response to the host. Initial screening for plant resistance normally involves quantities of diverse material. These studies are intended to distinguish broad differences in the effect on host or insect. In the case of sorghum and the sorghum stem borer, *C. partellus,* damage symptoms indicate activity of the insect on the host. On further testing of selected materials the evaluation system should permit more precise definition of the level and expression of resistance. Research on stem borer resistance at ICRISAT Center employs both levels of evaluation, since many sources of resistance have already been identified.

At Southern African Development Coordination Conference (SADCC)/ICRISAT, current investigations include identification of resistant sources and multilocational testing of material from ICRISAT Center known for its resistance. Since most of this resistance screening is done at national research stations without the benefit of an entomologist, an evaluation system is needed, one that is both simple yet accurate enough to detect subtle differences in susceptibility. The stem borer resistance screening method currently employed in these investigations is one developed at ICRISAT Center. It is biased toward an emphasis on deadheart formation and harvestable main heads. What is needed is a screening procedure that puts more emphasis on tolerance,

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without totally ignoring other resistance mechanisms. Experiences, in the SADCC region finding tolerance in material having desirable agronomic characteristics, seems to hold greater potential for this work. To date, suitable materials with appreciable level of antibiosis have not been found. In considering tolerance as a function of screening for resistance, it is important to consider symptoms of damage as they appear on the plant. These damage symptoms can then be further considered in relation to their value in a screening system.

Damage Done in Relation to the Life Cycle of *C. Partellus*

Chilo survives the dry season in larval diapause. As soon as sufficient moisture is available and temperature increases, the diapause is broken and the first generation of adults appears. Usually the first egg masses are found on sorghum seedlings 10-15 days after emergence. First-instar larvae climb from the oviposition site to the whorl, which they enter. They feed on the young and tender leaves near the base of the whorl. This feeding activity is later visible as elongated scars on the expanded leaves. This symptom is the first indication of the presence of *Chilo* larvae. Feeding activity continues in the whorl until the larvae reach the second and third instar (van Hamburg 1980). At this stage they stop feeding, leave the whorl, and migrate to the base of the seedling where they bore into the seedling base at soil level or a few centimeters above (Fig. 1a). Entry takes place about 8-10 days after hatching, depending on temperature. Feeding inside the seedling base causes two symptoms, depending on the position of the growing point (Taneja, ICRISAT, personal communication). If floral initiation has taken place and the apical meristem has moved upwards, larvae may feed only on the initial stem (Fig. 1 b). The symptom is stem tunneling. If the apical meristem is still present at the point of larval entry, it will be destroyed. The symptom will be a deadheart. This usually happens 30-45 days after germination, or 18-25 days after egglaying. With the death of the main stem, apical dominance has been removed, and a number of tillers form (usually two). The earlier these tillers form the greater the chance that they will synchronize with the main head development. If no deadheart is formed the larvae continue to tunnel below the growing point until pupation. This activity weakens the plant, making it susceptible to wind breakage. Pupation takes place in the stem. After about 30-40 days, one stem borer lifecycle is completed with the emergence of a new generation of moths. The second generation moths (if there are discrete generations; usually there are overlapping generations) will infest the plant again between 45-55 days after seedling emergence. The infestation pattern is the same. Larvae will infest the whorl, the second- and third- instars will move one or two internodes below the whorl (not to the base), and enter the stem usually at the leaf axis (Fig.lc). Larvae will feed on the already elongated peduncle, or on the closely packed internodes below the fully formed head if the head is still in the whorl. Stem tunneling will take place in both cases. If the peduncle is out of the whorl, feeding will not interfere with peduncle elongation. If the peduncle is not elongated, larvae will tend to feed on the closely packed internodes below the growing point (Fig.lc). In certain genotypes this interferes with penduncle elongation and the head may become lodged in the whorl. If peduncle elongation still takes place, larval feeding can damage vascular tissue. If so, incomplete grainfill and partial or complete chaffiness of the head may be observed. If none of these symptoms appear, larvae continue to tunnel the pith of the stem and peduncle. As long as feeding is restricted to the pith, grainfill will be normal or only slightly reduced. Weakened by tunneling, however, the peduncle may not be able to support the weight of the head, and becomes especially susceptible to wind damage. Peduncle breakage after physiological maturity will not reduce yield provided the peduncle remains affixed to the stem.

Superimposing Factors

Superimposing factors are those which interfere with or otherwise influence symptoms, such as drought, low soil fertility, and molds. For example, plant growth is affected, and damage symptoms appear when larvae feed on or near the apical meristem. If plant growth is slow due to drought or low soil fertility, damage to vital parts of the stem or the apical meristem can be influenced. In such a situation larval feeding progress may be more rapid than the development of new plant tissue. This prevents the growing point from moving ahead of the larval entry point.

Another superimposing factor is rotting. Larval stemfeeding in the pith normally does not interfere with plant growth. However, early-feeding activity is followed by rotting at an early stage of plant devel-

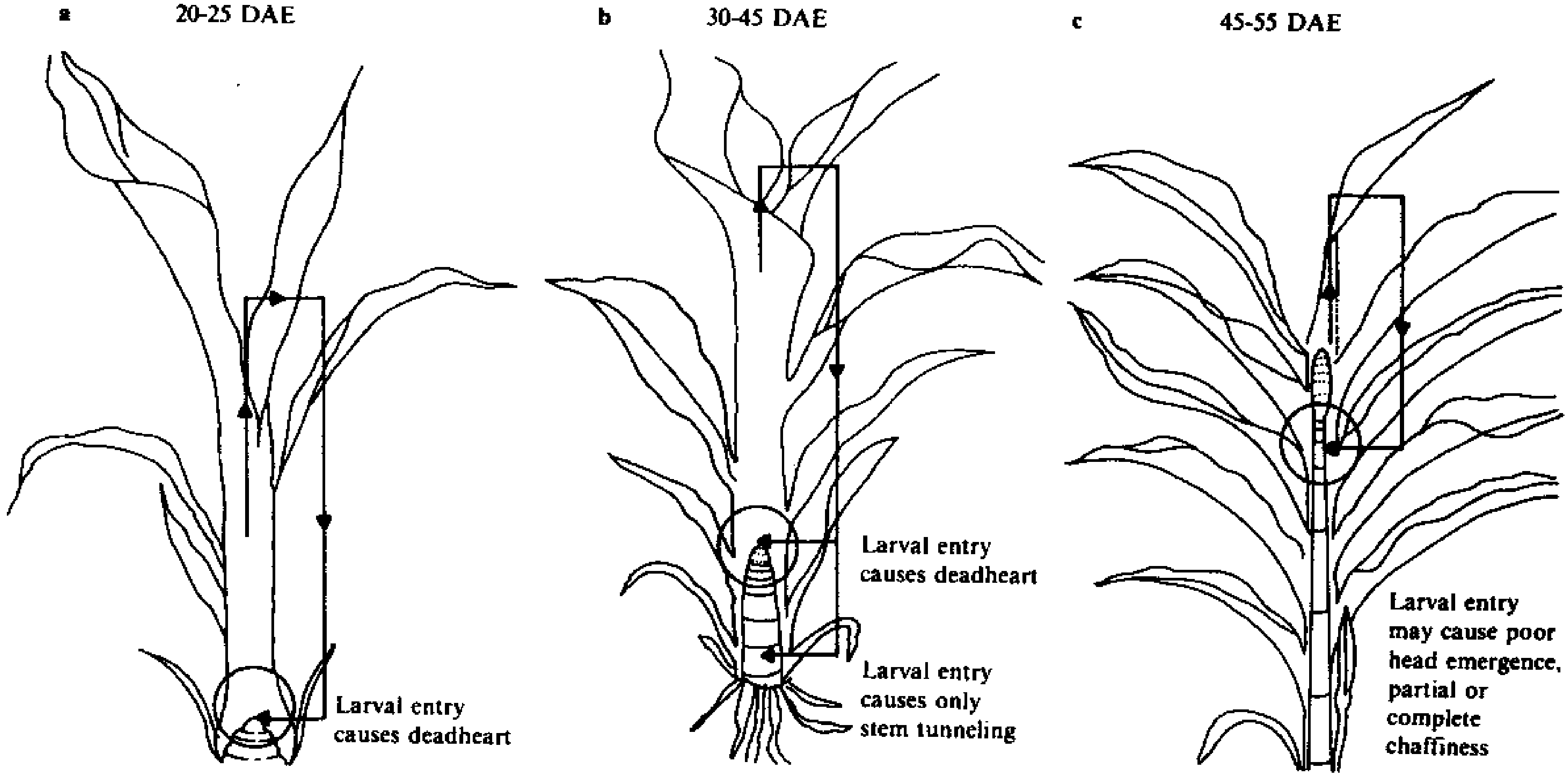

Figure 1. Larval movement and entry points in relation to plant growth stages: a) before panicle initiation, b) after panicle initiation, and c) flag leaf stage.

opment, vascular tissue may be damaged, and plant growth and grainfill may be completely or partially interrupted.

Damage Symptoms and their Value for Resistance Screening

Leaf Feeding

The present screening system only accounts for levels of feeding. Feeding level is rated on a scale, ranging from 1-5 or 1-10, depending on the preference of the scientist involved. From my experience this rating has little value for stem borer resistance screening. This is supported by Starks and Doggett (1970) who stated that leaf feeding rating was a poor indicator of expected grain yield. Results of their study are presented in Table 1. The reason for this may be that leaf feeding per se can involve many larvae yet have little impact on yield loss, while yield-limiting damage such as deadhearts and chaffiness can be caused by a single insect. Thus yield loss is not necessarily related to larval density. Rating leaf feeding along a crop row ignores the number of infested plants, and can even base a leaf feeding level on a single plant. Therefore, I suggest that the leaf feeding rating be dropped in favor of a count of the number of plants infested. This would give an indication of the uniformity of the infestation at any given point of time. A percentage of infested plants should be calculated at 25 days after emergence (DAE). This information would complement a shoot fly/deadheart evaluation. Multiple observations may be required to screen advanced resistant materials. I recommend two counts, 20 and 28 DAE.

Deadhearts

In all yield loss studies conducted at ICRISAT and in Zimbabwe, deadhearts are one of the most important factors contributing to yield loss. This parameter also gives a good indirect indication of plant growth status after floral initiation, if we consider the time of infestation in relation to deadheart formation (Fig.2). Deadheart formation is a function of

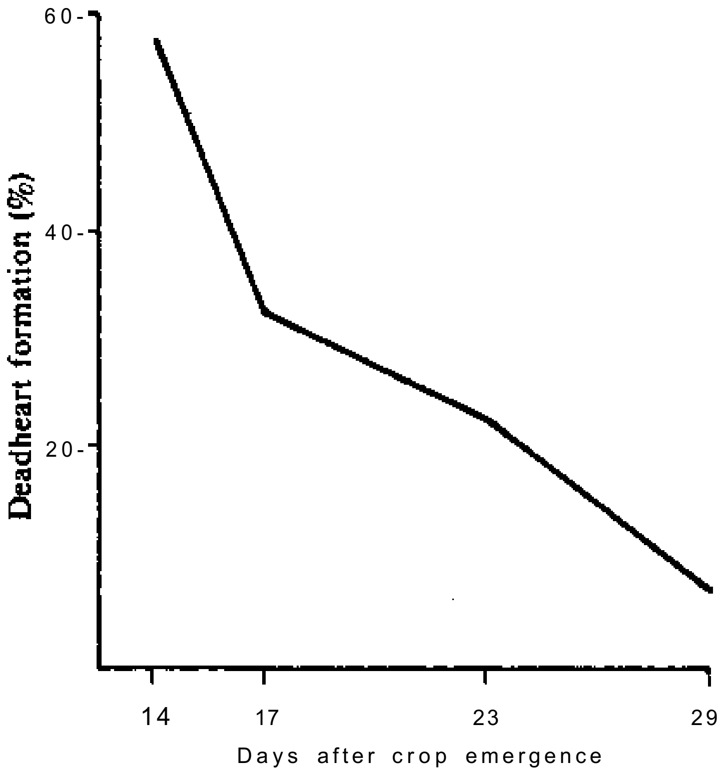

Figure 2. Deadheart formation in susceptible sorghum CSH 1 with larval infestation at 14,17,23, and 29 days after crop emergence (Taneja and Leuschner 1985).

Table 1. Mean rating of borer damage on CK 60 sorghum infested with 3 egg masses of *C. zonettus* plant^{-1} (4 replications)[1].

Infestation method	Rating leaf feeding[2]	No. of larvae stalk^{-1}	Tunnel length (cm)	Plant height (m)
No artificial infestation	2.2	0.4	3.3	69.3
Once in whorl	5.0	3.0	17.8	69.3
2 days apart in whorl	5.0	2.7	14.9	67.0
Weekly in whorl	5.3	2.9	9.1	69.5
2 days apart on leaves	5.7	1.8	16.5	59.2
LSD (P = 0.05)	2.5	0.6	6.6	7.4
CV(%)	28.2	17.8	91.7	19.0

1. Taken from Starks and Doggett (1970).
2. Rating from 1-9 with 1 = little feeding and 9 = severe feeding.

time of infestation (Taneja and Leuschner 1985). Therefore deadheart counts and time of infestation are essential parameters for an evaluation system. For a rapid screening resistance system, I recommend only one deadheart count, while for a more detailed screening, deadhearts should be counted twice (35 and 45 DAE). Early deadheart and late deadheart formation leads to tillering. The earlier tillers are formed, the greater the chance that they will synchronize with the main stem and produce high-yielding heads. Late tillers usually give little or no yield. Therefore, two deadheart counts and a shootfly deadheart count give an indication of the proportion of main tillers being formed early or late. Late tillering has implications for potential yield loss even without later stem borer infestation. For final yield evaluation, some criteria are necessary in tiller selection for practical purposes. I suggest that only tillers maturing up to 7-days after the main head should be sampled.

Stem Tunneling

Stem tunneling is a questionable parameter for stem borer resistance evaluation. Research at ICRISAT (Table 2) has demonstrated that stem tunneling does not correlate with yield loss if it does not lead to deadheart formation, poor head exertion, stem breakage, chaffy heads or peduncle breakage before or during grainfill (Taneja and Leuschner 1985). This was also reported by Starks and Doggett (1970). These damage parameters are a direct or indirect result of stem tunneling. Since they can be evaluated externally, and stem tunneling can only be measured by splitting the stem, I firmly recommend discarding stem tunneling as evaluation criteria for large-scale screening. Stem splitting should only be necessary for species identification and age distribution of stem borers, or in the case where fodder sorghum is evaluated for stem borer resistance.

Poor Head Exertion

Poor head exertion is an interesting damage criterion because it can be caused by genotypes, drought, or insect infestation. It definitely contributes to yield loss. To use it as an evaluation criterion for stem borer resistance, one has to be certain that the stem is severely infested. This can be done by stripping the top leaves and confirming borer-entry holes. In addition, one has to look at the overall appearance of this parameter. If it is uniformly distributed, in a few genotypes it may be genetic. If it is a common symptom across genotypes, drought may be a superimposing factor (it was common in 1986 in Zimbabwe, Malawi, and Tanzania where drought was prevalent). If poor head exertion is sporadic in a stand, it may be due to stem borers. In any case as it contributes significantly to yield loss, it should be adopted as an evaluation criterion.

Complete or Partial Chaffiness

Complete or partial chaffiness is another damage symptom that results from stem tunneling. The

Table 2. Effect of stem borer attack on head and grain yield of sorghum hybrid CSH 1 at Hisar, Haryana, India, 1982.[1]

Category	Mean stem tunneling (%)	Mean head weight (g)	Mean grain weight (g)	Ratio of grain to head weight (%)
No damage	0.0	61.6	52.7	85.3
Stem tunneling				
Up to 10%	6.1	62.3	53.2	84.2
10-20%	14.1	64.0	53.8	83.1
20-30%	26.3	84.6	69.0	81.5
30-40%	34.2	79.2	65.0	81.8
40-50%	43.6	69.2	55.2	79.3
50-60%	52.8	88.3	71.6	80.6
SE	±1.34	±10.49	±9.56	± 2.70
CV(%)	12	29	32	7

1. Source: Taneja and Leuschner (1985).

damage by stem feeding restricts photosynthates from passing to the head. This condition may be influenced by drought, as seen in the SADCC region in 1986. It is a straightforward damage criterion which has already been taken into consideration in the present evaluation system and should be retained.

Partial Grainfill

Partial grainfill is another difficult criterion to evaluate. It appears to be caused by a combination of drought and stem borer tunneling. I do not recommend it as a screening factor. In detailed yield loss studies its occurrence could be evaluated by comparing weight by volume samples.

Peduncle Breakage

This criterion may not be reflected in yield loss as long as grainfill is normal and heads have not dropped to the ground. As a screening factor, however, it reflects adequate strength of the peduncle, after boring, in relation to head size. Penduncle strength after boring may be an important consideration for sorghum breeders in avoiding long or weak peduncles in relation to head size. This criterion should be monitored and is useful in areas where wind damage is prevalent.

Stem Breakage

Stem breakage is an evaluation criterion which depends not only on tunneling itself but also on stem diameter, stem length, head size, and wind velocity. Normally stem breakage occurs late in the season, and may or may not result in grain loss. This condition is especially undesirable for mechanized harvest. Since it holds the potential for significant yield loss, stem breakage should be a criterion for screening resistance.

Peduncle Tunneling

Peduncle tunneling is part of stem tunneling. Since severe damage is reflected in chaffiness or peduncle breakage, it is not necessary for penduncle tunneling to be used as a distinct evaluation criterion.

Yield

Since yield is the ultimate criterion in assessing resistance (tolerance) I recommend its regular mea-

Table 3. Comparison of resistance screening procedures.

	Existing ICRISAT screening system	Proposed modified screening system
25 DAE	1. No. of plants	1. No. of plants
	2. No. of shoot fly deadhearts	2. No. of shootfly deadhearts
	3. Leaf feeding (score)	3. No. of plants with leaf feeding symptoms
35-45 DAE	1. No. of stem borer deadhearts	1. No. of plants 2. No. of stemborer deadhearts 3. No. of plants with leaf feeding symptoms
At harvest	1. No. of plants	1. No. of unproductive heads (evaluate main heads and tillers[1] separately)
	2. No. of main heads	Lump poor head exertion and chaffy heads together[1]
	3. No. of chaffy heads	2. Total no. of productive heads (evaluate main heads and tillers[1] separately)
	4. Stem tunneling (%)	3. No. of stems broken
	5. Internodes no. and no. bored	4. Peduncle breakage 5. Grain yield $plot^{-1}$ (taken from main heads and tillers)

1. Only tillers that mature up to 7 days after main heads should be taken into consideration.

surement in replicated trials. Even When we have only one row per replication it should at least be possible to get an indication of yield across replication and locations, in relation to existing stem borer damage parameters. If partially filled heads are present in trials we should assess yield by total grain mass as well as by volume ratios.

Proposed Screening System

Table 3 compares the existing resistance screening system developed at ICRISAT Center with a proposed, modified screening system. Contents generally reflect the discussion and recommendations made above.

Conclusion

The proposed modified screening system has, I believe, the potential to identify tolerance as a part of resistance. At the same time, this system can indicate the likely presence of antibiosis.

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Mechanisms of Stem Borer Resistance in Sorghum

S.L. Taneja[1] and S. Woodhead[2]

Abstract

*A number of sorghum genotypes resistant to the spotted stem borer (*Chilo partellus *Swinhoe) have been identified using natural and artificial infestations at ICRISAT. Resistance is attributed to ovipositional nonpreference and antibiosis mechanisms. The major plant characters identified include early panicle initiation and rapid internode elongation. In resistant genotypes, these factors were reflected in the success of first instar larval establishment in the leaf whorl, interval between hatching and larvae boring in the stem, larval mass, and survival rate. Success of the first instar larvae to establish in the whorl is also influenced by physical and chemical plant characteristics. A chemical factor in the surface wax of some sorghum genotypes is associated with larval disorientation.*

Résumé

Mécanismes de la résistance aux foreurs des tiges chez le sorgho : Un certain nombre de génotypes du sorgho ayant une résistance au borer ponctué du sorgho (**Chilo partellus**) ont été identifiés à l'ICRISAT grâce à des infestations naturelles et artificielles. Cette résistance est attribuée à une non préférence des femelles pour la ponte et à des mécanismes d'antibiose. Les principaux caractères impliqués sont l'initiation précoce des panicules et une élongation rapide des entre-noeuds. Chez les génotypes résistants ces facteurs ont influencé l'installation des larves de premier stade dans le cornet foliaire, l'intervalle de temps entre l'éclosion des oeufs et le moment où les larves pénètrent la tige, la quantité de larves mineuses et leur taux de survie. L'installation des larves de premier stade dans le cornet foliaire est également influencée par des caractéristiques physiques et chimiques de la plante. Un constituant chimique de la cire de surface de certains génotypes est responsable pour la désorientation des larves.

Introduction

Development of sorghum cultivars resistant to the spotted stem borer, *Chilo partellus* Swinhoe is one of the major research activities at ICRISAT. A number of sorghum genotypes resistant to *C. partellus* have been identified (Taneja and Leuschner 1985). Knowledge of these mechanisms of resistance is essential to fully understand and utilize resistant genotypes in the management of this pest.

All three types of resistance mechanisms (nonpreference, antibiosis, and tolerance) defined by Painter (1951) have been observed in sorghum genotypes resistant to *C. partellus* (Jotwani et al. 1971, 1978, Jotwani 1978, Lal and Pant 1980, and Dabrowski and Kidiavai 1983). Experiments have been

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conducted at ICRISAT Center under artificial infestation and at Hisar under natural infestation to differentiate resistance mechanisms and associated factors in a set of 20 genotypes, which have shown various levels of resistance/susceptibility to *C. partellus.* Experimental methods have been previously reported (Taneja and Leuschner 1985).

Ovipositional Nonpreference

This trial was conducted at Hisar during the rainy seasons of 1986 and 1987 under natural infestations. Egg laying observations were made at 3,4, and 5 weeks after crop emergence.

Total numbers of egg masses were significantly higher on the susceptible genotypes (ICSV 1 and CSH 1) than most of the resistant ones (Table 1). The lowest number of eggs (2-3 egg masses per 50 plants) were recorded on genotypes IS nos. 2309, 5538, 18551, 18573, 18580 in 1986, and on IS nos. 7224 and 8811 (14-26 egg masses per 50 plants) in 1987. Ovipositional nonpreference, as a mechanism of C. *partellus* resistance in sorghum has also been reported on some resistant genotypes by Lal and Pant (1980), and Dabrowski and Kidiavai (1983).

Table 1. Oviposition of spotted stem borer *Chilo partellus* on 20 sorghum genotypes under natural infestation, Hisar, rainy seasons 1986 and 1987.

1986		1987	
Genotype	Egg mass on 50 plants	Genotype	Egg mass on 50 plants
IS 1044	7	IS 2205	32
IS 2123	10	IS 2376	53
IS 2205	9	IS 4546	46
IS 2269	6	IS 5075	46
IS 2309	3	IS 5469	79
IS 4776	9	IS 5470	42
IS 5469	10	IS 5480	44
IS 5538	2	IS 5566	33
IS 5585	4	IS 5571	44
IS 12308	17	IS 7224	26
IS 13100	10	IS 8811	14
IS 13674	5	IS 17742	38
IS 18333	13	IS 17745	62
IS 18551	3	IS 17948	55
IS 18573	3	IS 18578	55
IS 18577	7	IS 18584	35
IS 18579	6	IS 18585	52
IS 18580	2	IS 18677	33
ICSV 1	25	ICSV 1	104
CSH 1	41	CSH I	110
SE	±4.4		±14.4
CV (%)	33		25

Establishment of Young Larvae in the Whorl

The success of newly hatched larvae of *C. partellus* in attaining the feeding site (plant whorl) varies with cultivar, and some resistant genotypes show a marked reduction in the proportion of larvae that establish on the plant. Various factors appear to be responsible for this tendency, including environmental effects (Bernays et al. 1983), and the physical and chemical characteristics of the plant (Woodhead and Taneja 1987).

Detailed observations in the field at ICRISAT Center showed that the climb to the whorl after hatchig was hazardous and, particularly on resistant genotypes, many larvae never reached their feeding site. Hatching normally occurs shortly after dawn when conditions are most favorable for success; there is usually little wind, and the temperature is low. In order to survive, larvae must reach the whorl expediently, avoiding desiccation as the temperature rises, or being blown off the plant as wind speed increases during the day. Also, the longer the time larvae spend crawling up the plant, the more susceptible they are to possible predators. Several physical characteristics of the resistant genotypes have been shown to affect the success of the larvae to reach the whorl, including a disorienting effect that has been attributed to the chemical composition of the surface wax of some cultivars (Woodhead 1987).

Physical Characteristics

Orientation of Leaf to Stem

Upward movement of *Chilo* larvae has been shown to result from positive phototaxis (Bernays et al. 1983,1985). As the larvae climb the culm they avoid the shadow cast by the leaves, thus follow a spiralling path around the culm. Susceptible genoypes have floppy leaves making an angle greater than 45° between the leaf and the culm, whereas resistant sorghum cultivars have very erect leaves which cast little shadow. On these genotypes, larvae continue upwards onto the leaves, rather than avoiding them. Once on the leaves they eventually crawl to the edge, and, on resistant genotypes the orientation of the edge trichomes is such that the larvae tend to move towards the leaf tip and from there disperse. Even on susceptible genotypes, some larvae will wander onto the leaves, fewer disperse after becoming reoriented at the leaf edge. Thus erectness of leaves and orientation of the leaf trichomes are physical factors that affect resistance to establishment. Cultivars with narrow, erect leaves have long been recognised by sorghum breeders as also resistant to snootily (*Atherigona soccata)* (Blum 1972). This characteristic is usually associated with glossiness, and is only expressed clearly in young plants about 15-20 days after emergence (DAE). In trials at ICRISAT Center and Hisar in 1982-84, when 20 genotypes were screened for resistance under artificial and natural infestations, and assessed for physical and chemical resistance characteristics, the only physical character common to all resistant genotypes was this trait of erect, narrow leaves (Woodhead and Taneja 1987).

Detachment of Leaf Sheath from Culm

Adults of *C. partellus* frequently lay their eggs on the underside of basal leaves of young sorghum plants from where the newly hatched larvae make their way to the culm. These lower leaves can become detached from the culm, a characteristic more noticeable in some genotypes than in others. Where detachment occurs, larvae have been observed to go behind the sheath, settle, and attempt to feed there. Although this is the favored feeding site for young larvae of *Sesamia* sp, most of which tunnel into the stem shortly after hatching, there is no evidence that young *Chilo* larvae can feed successfully on the tough culm, and insects that attempt to feed here rarely survive (Woodhead and Padgham,). Thus the tendency for detachment of the sheath from the culm can be an effective resistance mechanism to *Chilo* establishment.

Leaf Bases and Ligular Hairs

Detailed observations also showed that on approaching the base of a leaf, particularly on an erect-leafed genotype, there was a tendency for larvae to investigate the basal area of the leaves. On some genotypes the edges of the leaf base are tightly curled such that a small 'pocket' is formed that larvae can enter. Some larvae were observed to remain in these pockets for several hours. It has been postulated that host odor, humidity, and leaf color associated with this pocket are similar to those of the plant whorl, explaining the tendency of larvae to remain there. Larvae are also attracted to the leaf axil and frequently remain there for some time. Some genotypes have pronounced ligular hairs and it appears that larvae may become trapped in these hairs.

These types of mechanisms of resistance appear to be effective because they delay the larvae in an atmosphere of host odor and dark, simulating conditions in the whorl. Bernays et al. (1985) reported that the positive phototactic response, essential to maintain the directional climb to the feeding site, is labile and rapidly lost on entry to the whorl It is a similar effect to that reported for the silkworm *Bombyx mori on* mulberry, in which loss of phototactic response serves to keep the larvae on their host (Shimizu and Kato 1978). Sorghum genotypes on which this type of behavior is observed have lower rates of climbing success and lower final establishment rates, although climbing success has less impact in terms of crop loss to stem borer than leaf orientation.

Internode Length

Plant height affects larval success rates in that the further they climb, the more liklihood of desiccation or attack by predators, and the greater the exposure to unfavorable environmental conditions. This characteristic only operates as a resistance mechanism in plants where the internodal distances are large, and is particularly noticeable in native sorghums that are often tall and thin-stemmed in contrast to the short, high-yielding hybrids.

Surface Wax Effects

Sorghum plants develop a white bloom of epicuticular wax (Freeman 1970), which is variable in extent, and genotype dependent (Ayyangar and Ponnaiya 1941). It is clearly visible to the naked eye in some genotypes (e.g., CSH 1 and IS 1151) and in mature plants it forms a thick layer on the culm. It has been shown that when this wax layer is conspicuous, it affects climbing by *Chilo* larvae (Bernays et al. 1983). Larvae accumulate wax around their prolegs as they move over the plant surface which impedes their progress. Larvae have been found to climb almost twice as fast on stems of IS 1151 from which the wax had been removed, compared with stems prior to removal of wax. Thus surface wax can have a gross effect on larval success rates, although under wet conditions the superficial wax is often washed off plants in the field. In general, larvae climb more slowly and have a lower success rate on wet plants, an added factor which complicates interpretation of the importance of a thick wax layer in resistance.

In addition to the gross effects of thick surface waxes on larval movement, it has been shown that on some resistant genotypes there is a disorienting effect which has been attributed to the chemical composition of the epicuticular wax (Woodhead 1987). It was first observed on young plants of IS 2205 during field studies at ICRISAT Center. After egg hatch, larval progress towards the whorl was monitored. Although the primary stimulus was positive phototaxis on all genotypes studied, on IS 2205 a behavior pattern was observed which was characterized by hesitation, circling, and stopping completely for periods of up to several minutes. All these activities were accompanied by raising and side-to-side motion of the head and upper abdomen in a searching movement. Apparently, insects were not biting as they crawled over the plant surface, but were receiving cues from it which reinforced their upward movement on susceptible genotypes, and disoriented them on resistant ones. Examination of the surface of resistant and susceptible genotypes by scanning electron microscopy revealed differences in epicuticular wax morphology, which were known to indicate differences in chemical composition (Baker 1982). Detailed analysis of surface wax extracts showed a similar composition for all genotypes with the exception of a consistent concentration difference in a compound that co-eluted with the 32 carbon n-alkane. This compound was present in very low amounts in the wax of IS 2205, whereas in IS 1151 and CSH 1 waxes, the concentration was more than double. It appears that larvae of *Chilo* identify their host plant by chemical cues received as they crawl over the plant surface. If any of the cues is missing, or not sufficiently strong, the insect is disoriented, the upward climb is interrupted, and fewer larvae are successful in reaching the whorl and establishing on the plant.

Plant Growth Characteristics

Plant growth was monitored through destructive samplings at 2-day intervals up to panicle initiation stage, and at weekly intervals thereafter, recording plant height, number of leaves, panicle initiation, number of internodes, shoot length, and panicle length. The most significant parameters in resistant genotypes were found to be the time taken for panicle initiation, and shoot length (Table 2). Although it took more time for panicle initiation during the rainy season, similar trends were observed in most of the genotypes. Genotypes with early panicle initiation escape deadheart formation due to inability of larvae to reach the growing point which would already have pushed up above larval entry point. Thus although larvae may feed in the stem and cause tunneling, this activity alone may not cause deadhearts, the critical damage which is associated with grain yield loss. Genotype IS 12308 had very early

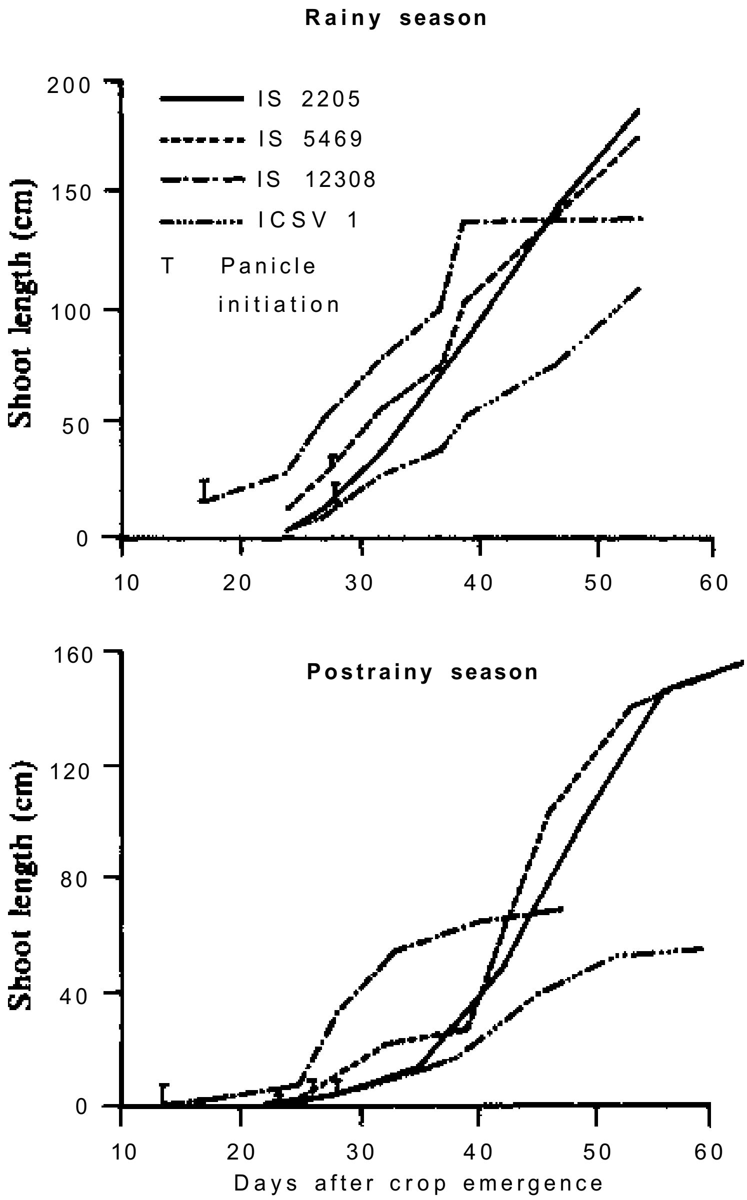

Figure 1. Shoot length and panicle initiation of four sorghum genotypes in relation to age of the crop, ICRISAT Center, rainy and postrainy seasons 1984/85.

panicle initiation (12 days in postrainy and 17 days in rainy seasons). Although, the final shoot length in this genotype has been similar to the susceptible genotype ICSV 1 (Fig. 1), it is still resistant to deadheart formation because of the shorter time taken to panicle initiation.

Shoot length, i.e., faster internode elongation, has been observed as a significant growth characteristic in stem borer resistance. This characteristic also pushes the growing point upward, hampering the ability of larvae to reach it, and thus preventing deadheart formation. In the present study, a number of resistant genotypes with similar panicle initiation time escaped deadheart formation due to faster internode elongation. For example, two resistant genotypes, IS 2205 and IS 5469, having panicle initiation similar to susceptible ICSV 1, had greater shoot length during its growth period in both seasons (Fig. 1).

Insect Biological Parameters

In a study on the effect of sorghum genotypes on insect biology, using blackhead stage eggs to infest plants 15-20 DAE, it was found that among the parameters measured, the most significant ones were first-instar larval establishment, time interval between larval hatching and boring into the stem, larval mass, and survival rate. A lesser proportion of larvae became established in the whorl in some of the resistant genotypes (Table 2), for example, in genotypes IS 12308 (25%), IS 13100 (39%), IS 2269 (40%), compared with ICSV 1 (51%) and IS 18573 (77%). Chapman et al. (1983) and Bernays et al. (1983) observed marked differences in the establishment of first-instar larvae among resistant and susceptible cultivars.

In some resistant genotypes, it took more time for the larvae to arrive at the base of the stem for boring.

Table 2. Factors associated with stem borer resistance in sorghum, ICRISAT Center.

Genotype	Borer dead-hearts	Days for panicle initia-tion	Shoot length (cm) 28 DAE[1]	Larvae recovered in whorl (%) DAP	Larvae recovered in stem 10 DAI	Larval mass (mg $larva^{-1}$) 21 DAI	Total insects recovered *(%)* 28 DAI
IS 1044	44	53	15	54	9	92	28
IS 2123	27	33	21	54	7	93	15
IS 2205	51	39	13	57	16	103	9
IS 2269	-	33	11	40	17	127	22
IS 2309	40	30	14	53	35	85	8
IS 4776	41	40	9	44	10	109	20
IS 5469	22	33	26	57	11	98	25
IS 5538	-	56	6	56	12	99	22
IS 5585	51	33	19	41	9		15
IS 12308	43	17	50	25	31	89	21
IS 13100	45	25	46	39	7	88	18
IS 13674	55	28	24	64	24	101	26
IS 18333	65	53	10	58	21	85	10
IS 18551	48	38	12	62	10	109	23
IS 18573	49	56	6	77	10	140	20
IS 18577	58	51	8	41	21	84	21
IS 18579	49	40	8	42	13	92	15
IS 18580	55	40	11	57	12	99	19
ICSV 1	76	33	10	51	17	115	20
CSH 1	63	28	9	42	13	94	24
Mean				51	15	99	19
SE				±6.5	±4.3	±6.5	±4.5
CV(%)				18	45	9	33

1. DAE = days after crop emergence.
2. DAI = days after infestation.

This may be due to nutritional content of particular genotypes which may prolong the larval period. In genotypes IS 1044, IS 2123, IS 5585, and IS 13100, less than 10% of the larvae were observed at the base of the plant 10 days after the infestation, compared with 21 % on IS 18333 and 35% on IS 2309 (Table 2). Prolongation of larval period on resistant genotypes was also reported by Jotwani et al. (1978).

Larval mass was significantly lower (<90 mg $larva^{-1}$) in six genotypes (IS 2309, IS 5585, IS 12308, IS 13100, IS 18333, and IS 18577) compared with IS 18573 (140 mg $larva^{-1}$), and ICSV 1 (115 mg $larva^{-1}$).

Survival rate, measured by the total insect recovery, was significantly lower in IS 2205, IS 2309, and IS 18333 (8-10%) compared with 28% in IS 1044 and 24% in CSH 1. Low survival rate of *C. partellus* on resistant genotypes of sorghum have also been observed by Lal and Sukhani (1979).

Parameters studied indicate antibiosis mechanisms involved in borer resistance, which have also been observed by many workers (Jotwani et al. 1971, 1978, Lal and Sukhani 1979, and Dabrowski and Kidwai 1983). The present study also indicates that different combinations of factors are involved in confirming stem borer resistance in various genotypes. This information is vital for borer resistance breeding programs.

Tolerance

Jotwani (1978) reported significantly lower yield loss to stem borers in breeding selections such as 124, 175, 177, 446, 447, 731, 780, 827, and 829, than in CSH 1, and attributed this to tolerance mechanism. In spite of severe leaf injury and stem tunneling in these selections, the final plant stand was very good and most of the plants had normal panicles. Similar results were obtained in genotype IS 2205 by Dabrowski and Kidiavai (1983).

Conclusion

Ovipositional nonpreference, antibiosis, and tolerance type of mechanisms exist for stem borer resistance in sorghum. The major plant characteristics associated with resistance are early panicle initiation, and faster internode elongation. Reduced larval establishment in the leaf whorl, longer time interval between larval hatching and boring into the stem, lower larval mass and survival rate have been observed in resistant genotypes. Several physical (leaf orientation, leaf sheath detachment, leaf bases and ligular hairs, and internode length), and chemical characteristics of the resistant genotypes have been shown to affect the success of the larvae to reach the whorl, including a disorienting effect. Different combinations of factors are involved in conferring resistance in a particular sorghum genotype. This infomation is vital for borer resistance breeding programs, where resistant sources with diverse mechanisms may effectively be used either in a pedigree or population breeding approach.

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Considerations in the Development of a Host-plant Resistance Program Against the Pearl Millet Stem Borer

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Abstract

*The stem borer (*Coniesta ignefusalis,*) is a key pest of pearl millet in the Sahelian region of West Africa. Several cultivars and breeding lines appear to sustain lower populations of this insect compared to local landraces. These differences have not been quantified in trials designed to measure levels of insect resistance. The major constraint in these trials is the nonuniform distribution of natural infestations. In experiments at the ICRISAT Sahelian Center, emphasis is being placed on 1. developing methods to augment natural populations, 2. establishing population levels that give repeatable and statistically significant results, 3. determining optimum plot size, 4. determining the sample size needed to measure differences at various population densities, and 5. determining economic thresholds for levels of resistance needed to avert economic losses.*

Résumé

Techniques de criblage du mil pour la résistance aux foreurs des tiges : Le foreur des tiges du mil, Acigona ignefusalis, *est le principal ravageur du mil dans les régions sahéliennes d'Afrique de l'Ouest. Il semble que plusieurs cultivars et lignées en sélection hébergent des populations de foreurs inférieures à celles observées sur des variétés locales. Ces différences n'ont pas été quantifiées lors des essais visant à mesurer le niveau de résistance à cause de l'hétérogénéité des infestations naturelles. Les essais menés au Centre sahélien de l'ICRISAT sont axés sur : (1) la mise au point des méthodes permettant d'augmenter les populations naturelles; (2) la détermination de niveaux d'infestation donnant des résultats reproductibles et statistiquement significatifs; (3) la détermination de la taille optimale des parcelles; (4) la détermination de la taille de l'échantillon permettant la mesure des différences à diverses densités de population et (5) la détermination des seuils économiques pour des niveaux de résistance permettant d'éviter des pertes économiques.*

A review of the literature shows that sources of insect resistance has been found for the major plant pests which attack important agricultural food crops. For more than 100 insect species, sources of plant resistance have been identified (Harris and Frederiksen 1984). Even so, few insect-resistant cultivars are actually being grown. The reason for this apparent disparity is pertinent to this presentation. The HPR program at ICRISAT Sahelian Center in Niamey, Niger, is currently being organized to work with pearl millet, *Pennisetum americanum,* and will become operational in 1989. By this time certain

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basic studies will have been completed which are fundamental to a successful H PR program. Some of the concepts and principles being considered for this program are presented.

The Search for Sources of Resistance

The search for plants resistant to insects is the first step towards developing a pest-resistant cultivar. Most groups of potentially useful breeding stock are so large, that screening every genetic variant or available accession is impractical. In the case of millet, more than 15000 germplasm accessions are available for screening. If 1000 were screened each year, it would require more than 15 years to complete the process. Now entries are being added every year, therefore compromises must be made when selecting lines to be screened for resistance. These decisions are especially important to developing a pest-resistant cultivar, since the end-product is principally dependent upon the initial choice of potential resistant sources.

The search for resistance should be conducted to obtain the best sources of resistances with a minimum expenditure of money, time, effort, and manpower. Painter (1951) in his book "Host Plant Resistance," suggests that host resistance should be sought first within the crop species and secondly from the closely related species that will produce fertile progeny when crossed. He also advocates using those lines which are adapted to an area where the resistance is to be used. However, this approach does not optimize the chance of finding the best source of resistance unless these sources are randomly distributed.

The continued presence of an insect in a system indicates that it has been able to overcome defense strategies that the plant developed. If this is the case it is not likely that the insect population has adversely affected the plant for a significant period of time. Defence mechanisms that the plant has been able to develop probably co-evolved with the pest. If this did not happen, the insect would probably have never reached the status of a pest.

Most sources of host resistance to insects presently being utilized in agriculture consist of plant material that have evolved in the absence of insects to which they are resistant (Harris 1980). Resistance in these instances is fortuitous and has a pleitropic basis since evolutionary selection has not been involved. Useful resistance is so important that it must be obtained from any available source, especially those sources offering the greatest probability of success. A generally held assumption, not always applicable, is that the most likely source of resistance is from areas where an insect is endemic.

Regardless of the origin of resistance, it is of limited use if it is not: (1) heritable; (2) relatively permanent; and (3) compatible with desired agronomic qualities. If these three conditions do not exist, the resistance source may never be utilized even though the plant may actually be immune to insect attack (Harris and Frederiksen 1984).

Identification of Resistance

Many different systems have been used to identify plant resistance to insects. Some are based on observations of plant populations subjected to a pest epidemic. Valuable information can be obtained from such observations, but carefully designed experiments are needed to measure insect populations on the host before deciding whether the plant is resistant. By definition, a plant that supports fewer pests than another plant, but suffers unacceptable losses, cannot be considered as resistant. The mechanisms, however, that result in reduced insect populations may provide valuable selection criteria in the development of an insect-resistant plant. These are the products of research.

General Knowledge of the Biology of the Target Pests

It is important to know the number of generations a pest has each cropping season, as well as the relative rate of increase per generation that the pest undergoes. Tables 1,2,3, and 4 illustrate the importance of this information in designing a suppression program based on chemical control or host-plant resistance.

Note from Table 1 that strategies needed to control an insect with a 10-fold rate of increase will be different from those needed to control a pest having only a 2-fold rate of increase. Without this information, it would be difficult to know levels of plant resistance necessary to avert economic losses.

The number of generations that a pest undergoes during the cropping season is equally important. Table 2 illustrates this point showing 10- and 5-fold rates of increases for five consecutive generations during a growing season. It is obvious that strategies used *to* suppress an insect with two generations per year and a 5-fold rate of increase would be different from one having five generations a season with a 10-fold rate of increase.

There have been numerous studies on the field biology of the millet stem borer *Coniesta* (*Acigona*) *ignefusalis* which can contribute to the development of an insect-resistant plant. For example, field studies indicate that, in most of the range occupied by the millet stem borer, there are two generations per year, and that the rate of increase per generation probably does not exceed 10-fold.

Table 3 shows natural mortality in a stem borer population taken from millet stalks left standing in the field. Survival of this insect is greater in stalks left standing in the field than in stems exposed to high soil surface temperatures (Harris 1962). Since it is common practice by growers to uproot millet plants during the dry season, the degree of mortality will be much greater than that shown in Table 3.

A conservative estimate would be that less than 500 larvae per hectare survive the postrainy season. Other factors such as irregular emergence patterns, and the inability to find a mate within the short life span of the adults, tend to support this estimate. Using this figure (500) as a realistic estimate, we can project the populations that we must deal with in the development of millet that is resistant to stem borer (Table 4). Levels of resistance that will be needed to maintain a stabilized population during the growing season can also be projected (Table 5). The unknown quantity in this exercise is the levels of infestation that can be tolerated before economic losses occur. However, it would not be unrealistic to expect this

Table 1. Levels of suppression needed to stabilize a population with different rates of increase (Knipling 1979).

Net increase potential per generation	Percentage of control levels above normal hazards required for each generation to stabilize a population
20	95
10	90
5	80
3	67
2	50

Table 2. Rate of increase of two insect populations for five consecutive generations.

Generation	5-fold increase rate	10-fold increase rate
1	100	100
2	500	1 000
3	2 500	10000
4	12 500	100 000
5	62 500	1000 000

Table 4. Estimated population levels of the millet stem borer under naturally occurring conditions.

No. adults ha^{-1} surviving to infest new crop	500
First generation	5000
Second generation	50 000

Table 3. Summary of dry stem examination for diapause larvae of *Coniesta* (*Acigona*), ICRISAT Sahelian Center, Sadore, Niger, 1986/87 dry season.

Month	No. of stems examined	No. of live larvae	No. of larvae $stem^{-1}$	Estimated population ha^{-1}	Reduction (%)	No. of pupae
Nov	1725	2711	1.57	51 810	-	0
Dec	2075	2400	1.16	38 280	26.1	0
Jan	1350	1078	0.79	26 070	49.7	0
Feb	1700	1578	0.93	30 690	40.8	0
Mar	1775	1186	0.66	21 780	58.0	0
Apr	1645	655	0.4	13 200	74.2	0
May	1100	328	0.3	9 900	80.9	0
Jun	825	168	0.2	6600	87.3	0
Jul	921	48	0.05	1 716	96.7	82[1]

1. First pupae found during the week starting July 7. 1987.

Table 5. Different levels of suppression and influence on rate of increase of an insect with 10-fold rate of increase per feneration.

Generation	Uncontrolled population	Suppression/generation (%)		
		50	80	90
1	5000	2500	1000	500
2	50000	125000	2000	50

level to be less than 10 000 larvae per hectare, in which case the level of resistance needed would be less than 80% and should be an attainable goal.

Methodology for a HPR Program

A host-plant resistance program begins with collections that have characters or traits that are unknown. This is complicated by the variability that can be expected within an entry, since many plant introductions are hetergenous. Harris and Frederiksen (1984) listed three criteria that are pertinent to any screening program designed to detect plant resistance:

1. Field studies should ensure that the stressing agent is uniformly distributed.
2. Resistance should be expressed by a component of the population being screened.
3. The epidemic should not overwhelm the factors that contribute to resistance.

With lepidopterous insects, populations tend to be clumped, so infestations are not uniform within the test area. Failure to have this capability could result in a failed program. This can be illustrated by an example from a program that was designed to find resistance to the cotton leafworm, *Alabama argillicea* Hub. In a nonreplicated screening trial, 2200 entries were planted, with 10% of the entries as susceptible standards. Of these standards, 27% were rated as being resistant and the remainder were rated susceptible. In this test the standard was truly susceptible but the insect population was so poorly distributed within the test area that no meaningful results could be obtained. Relating this example to the millet stem borer, a clumped distribution within the test area could be even more problematic as the insect is a much weaker flyer than the cotton leafworm (moth).

Early in our work, we recognized this problem of uneven distribution and assigned high priority to a facility to rear the millet stem borer. When completed, it will have the capability to produce large numbers of eggs or first-instar larvae that can be used to obtain a uniform level of infestation in screening trials. Other methods of augmenting the natural populations are being investigated, such as distributing stalks containing diapausing larvae at different densities within the test blocks. This method, however, does not have the precision that can be obtained using eggs or newly hatched larvae.

The level of infestation that is desirable for screening purposes has not been determined, but this level will probably be 50% of infested plants within the plot. The problems of "over-infesting", and masking low levels of resistance, must be considered. It is unlikely that singular materials will be found which can impart a desired level of resistance. Several different sources of resistance must be found, that can be accumulated to achieve the desired level of suppression.

Methodology to Incorporate Resistance into Elite Lines

Numerous sources of plant resistance have been identified but only a few have been incorporated into agronomically acceptable cultivars. The principal reason for this apparent disparity is probably the inability to recover resistant factors in segregating populations. Techniques appropriate for field and laboratory screening of resistant or susceptible lines may not be appropriate for recovering resistant plants in a segregating population. Only rarely will a resistant source be found in an agronomically acceptable cultivar. More often, resistance must be transferred from an unimproved parental source to one that is agronomically acceptable.

When resistant and susceptible lines are crossed, the inheritance will fall into one of three categories:

1. Major genes which show typical Mendelian ratios in F2 generations.
2. Minor genes that continue to show variation for resistance level in segregating populations.
3. Combinations of major, minor, and modifier genes. Harris and Frederiksen (1984) indicate that the inheritance of resistance has been worked out in only 33 of more than 100 species of reported insect-resistant plants. From this group, resistance was dominant in only 17 species, suggesting that most sources of insect resistance will be of a recessive nature, or controlled by minor or modifier genes. To recover these resistant genes

in segregating populations, precise methods are needed, methods that are generally not available. This factor alone may account for the lack of resistant cultivars, even though good resistant parental sources have been identified.

Discussion and Conclusion

The probability of developing a millet cultivar for West Africa that is truly stem borer-resistant is good for a number of reasons. First, the insect has only two (under most conditions) generations each growing season. The overwhelming population pressures that result from insects that have four or five generations per growing season are lacking. Second, there is no evidence of long-range migration, so researchers will be dealing with local populations. Third, there is not a complex of stem borers in most of the Sahelian region, therefore if a resistant source could be utilized for population suppression there will not be another borer to fill the "niche" that was occupied by *C. ignesfusalis.* Finally, ICRISAT's millet germplasm bank contains more than 15 000 accessions of which approximately 50% originated outside the area that is occupied by the millet stem borer.

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Discussion

Saxena: Dr Wiseman showed that the nonpreference of the army worm for different resistant sorghum varieties could be for feeding or for oviposition. But, we find that a third aspect of nonpreference may be for orientation to plants, as distinct from orientation to nonplant characters or settling response.

Wiseman: I showed a general overview of nonpreference. Yes, when nonpreference is broken down into the various factors, orientation would certainly be included.

Lukefahr: What is the relationship between the greenhouse, whorl, and panicle resistance tests? If you select 100 lines in a greenhouse test, how many exhibit whorl and panicle resistance in subsequent tests?

Wiseman: Probably very few, if any. It is extremely useful to find resistance to more than one stage of plant development.

Nwanze: Does the methodology you use in greenhouse screening permit you to identify material with moderate levels of resistance, since you rate your test material only after the susceptible control reaches a rating of 9?

Wiseman: Yes, I simply observe the material earlier or slightly before the susceptible control approaches a 9 rating. But our goal was to find higher levels of resistance than the resistant control.

Saxena: How did you do the wax coating on the surface? What was the experimental design to explain larval movements?

Woodhead: Leaf models were prepared and the surfaces were waxed for measuring the larval movement. Speed and the direction of the larval movements were also ascertained.

Vidyabhushnam: What selection criteria should be followed for breeding sorghum for resistance to *Child?* In my opinion leaf feeding is the best method.

Ajayi: In Nigeria, we have a complex of borers attacking sorghum. *Sesamia does* not feed on leaves, so leaf damage cannot be generalized as a criterion for screening.

Taneja: The main criterion is deadheart of seedlings, which is highly correlated to yield loss. I suggest that the test material be planted at peak pest activity in the hot spot areas. Where possible, use uniform artificial infestation.

Leuschner: Leaf feeding scores should be done twice, as deadheart formation depends on many factors.

Guthrie: Deadheart alone is not dependable, leaf feeding should be taken into consideration while selecting a line.

Nwanze: I think it is necessary that we also look at leaf feeding resistance during the whorl stage. A high level of leaf feeding resistance, whether nonpreference or antibiosis will certainly reduce larval population and consequent deadheart formation. We need to identify what type of resistance we are dealing with. We should also remember that we are talking about HPR as a component in the management of stem borers. Do we then need very high levels of resistance? Do we need to produce cultivars with less than 25% deadhearts?

Srivastava: Has anyone observed the behavior of a *C. partellus larva* where it simply cuts an incision on the growing point and goes away? The cutting of the growing points leads to the formation of deadheart, but the rest of the plant does not show any damage symptom.

Saxena: Yes, we have observed this phenomenon.

Seshu Reddy: All damage parameters must be taken into consideration for the evaluation of a line. With only one parameter it is difficult to adequately evaluate stem borer resistance in a cultivar.

Breeding for Resistance

Screening and Breeding Rice for Stem Borer Resistance

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Abstract

Progress on the development of rice varieties with resistance to stem borers in Asia has been slow. The reasons for this are the lack of suitable germplasm and screening techniques and a poor understanding of the genetics of resistance. In spite of this, efforts have been made at national and international levels to accumulate genes from moderately resistant genotypes. Such genotypes include ARC 6107, ARC 6044, RYT 2908 (vegetative stage), ARC 6215. ARC 6579. ARC 5757 (heading stage), and ARC 5500, Manoharsali (vegetative and heading). In multilocational testing, promising breeding lines have also been identified from crosses such as Phalguna x TKM 6 (RP 2199) and Swarnadhan x Velluthacheera (RP 2068). Resistance in Phalguna x TKM 6 appears to be polygenic. Moderately resistant varieties like IET 2815, IET 2812, IET 31I6, and IET 3127 are useful in integrated pest management programs.

Résumé

Criblage et sélection du riz pour la résistance aux foreurs des tiges : La création de variétés de riz ayant une résistance aux foreurs des tiges n'a pas connu un progrès rapide faute de ressources génétiques et de techniques de criblage appropriées et à cause d'une mauvaise connaissance de la génétique de la résistance. Toutefois, des travaux ont été menés au niveaux national et international pour rassembler les gènes issus de génotypes ayant une résistance moyenne, dont : ARC 6107, ARC 6044, RYT 2908 (stade végétatif), ARC 6215, ARC 6579, ARC 5757 (stade d'épiaison) et ARC 5500, Manoharsali (stades végétatif et d'épiaison). En essais multilocaux, les lignées prometteuses en sélection ont été également repérées; elles sont issues des croisements tels que Phalguna × TKM 6 (RP 2199) et Swarnadhan × Velluthacheera (RP 2068). Le croisement Phalguna × TKM 6 semble donner une résistance moyenne telle que IET 2815, IET 2812, IET 3116 et IET 3127 sont utiles pour les programmes de lutte intégrée.

Introduction

More than 20 species of rice stem borers, mainly Pyralidae and Noctuidae, constitute the major insect pests on rice throughout the world. In India, the yellow stem borer *Scirpophaga incertulas* Walker is the most predominant species and occurs in most of the rice-growing areas of the country. Another species, *Sesamia inferens* Walker, the pink borer, has assumed importance particularly in hilly areas of Uttar Pradesh. Other species, which cause concern only in certain years, include striped borer *Chilo suppressalis* Walker, the dark headed borer *C. polychrysus* Meyrick, and the white borer *S. innotata* Walker.

Several estimates are available on yield losses due to stem borer damage (Mathur 1983). Experiments at the Central Rice Research Institute (CRRI), Cut-

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tack, India revealed that a 1% increase in deadhearts decreased yield by 0.28% and every unit increase in white earheads resulted in a yield loss of 0.624%. Combined damage of deadhearts and white earheads resulted in a 0.355% yield reduction. Damage simulation studies at the International Rice Research Institute (IRRI), Philippines indicated that 10% deadhearts under greenhouse conditions caused yield losses of 10%, while 10% deadhearts under field conditions resulted in 5% yield loss. On an average, stem borer damage in tropical Asia is estimated to cause 5-10% losses, while in India 3-95% losses are reported. Field experiments in endemic areas, in plots protected against stem borer damage, realized additional grain yields of 500-1000 kg ha^{-1}. (AICRIP 1986).

Though rice varieties have been known to display differential reactions against stem borers for more than 70 years, progress on development of resistant varieties is relatively slow and not spectacular. Early attempts made in this direction have been reviewed by Israel (1967) for India, Pathak (1967) for the Philippines, and by Munakata and Okamoto (1967) for Japan. More recent work in Asia is covered by Heinrichs (1980) while Choudhary et al. (1984) exhaustively reviewed the status of varietal resistance in Asia. In this paper we summarize recent research on the identification of resistant donors and promising breeding lines at the All India Directorate of Rice Research (DRR), Hyderabad, and under its All India Coordinated Rice Improvement Program (AICRIP) at multilocations.

Screening Rice Germplasm and Breeding Lines at DRR

Taking advantage of consistently high levels of yellow stem borer incidence during both wet (rainy season) and dry (Postrainy season) seasons in experimental farms at Rajendranagar and Ramachandrapuram, a total of 289 germplasm entries were evaluated. Based on intitial screening from the 1980 rainy season, 36 selected entries were further tested for six consecutive seasons (1981 postrainy season through 1983 rainy season).

During each of these seasons, selections were made of at least 10 damage-free plants (no deadheart and/or white earhead) in each of the promising entries. Progenies of these plants were tested the following season at both test locations. Entries were evaluated on a percentage basis of affected plants. Performance of a test entry was considered promising if plant damage did not exceed 60% at vegetative stage or 15% at heading stage. During the 1984 postrainy season, the seventh season of testing, test entries were finally rated for their performance.

The highest damage among the test entries recorded at vegetative stage during the course of evaluation ranged from 66% (ARC 6158 and ARC 6579 during the 1981 rainy season) to 93% (ARC 15831 during the 1981 postrainy season). At heading stage, highest damage ranged from 44% (ARC 6215 during the 1982 rainy season) to 62% (ARC 6107 during the 1981 rainy season). Despite selection of damage-free plants during every generation, only 5 entries out of 36 tested showed relatively consistent performance in at least one of the growth stages during 3 or more testing seasons (Table 1).

Plant damage in the most promising entries during the 1984 postrainy season (Table 2) highlighted

Table 1. Performance of selected rice germplasm entries against the stem borer.

	No.of seasons recording promising[1] reaction at	
Entry	Vegetative stage	Heading stage
Manoharsali	6	5
ARC 5500	5	6
ARC 6107	6	
ARC 6044	4	1
ARC 6215	4	
ARC 6579	2	4
ARC 5757	4	3

1. With less than 60% damaged plants at vegetative stage or 15% at heading stage.

Table 2. Percentage damage in selected germplasm accessions by stem borer, postrainy season, 1984.

	Damage (%) at	
Entry	Vegetative stage	Heading stage
Manoharsali	33.5	3.7
ARC 5500	51.9	12.3
ARC 6215	57.2	33.9
ARC 6579	68.7	5.0
ARC 5757	71.0	8.2
TKM 6	60.7	19.6
IET 2815 (Sasyasree)	39.2	17.8
Jaya	60.7	30.3

the performance of new donors compared with the standard resistant control TKM 6 and the released resistant variety Sasyasree. Two of the donors, Manoharsali and ARC 5500, displayed better reaction at both vegetative and heading stages, while ARC 6579 and ARC 5757 showed a lower level of damage at heading stage. Reaction of these donors was better than the resistant control TKM 6. ARC 6215, despite consistency in earlier testing, showed only marginal resistance at vegetative stage, and both ARC 6107 and ARC 6044 showed higher damage than in earlier testing. Further studies on the extent of damage and mechanisms of resistance in selected varieties are in progress.

Multilocational Tests

AICRIP multilocational varietal screening trials against stem borers were reintroduced in 1983 with the contribution of promising donors and breeding lines from different institutions and universities. A total of 142 entries have been tested so far at 10-20 test locations across the country.

Since the severity of pest load at test locations varied considerably, entries were chosen for retesting on the basis of their relative performance over locations. Four years of testing identified 7 donors and 6 breeding lines with consistency in performance over locations (Table 3). Significantly, four of the donors, Manoharsali, ARC 5500, ARC 6044, and ARC 6215, selected on the basis of their evaluation at Hyderabad, continued to display good performance in multilocational testing. Good pest resistance was also seen in RYT 2908 at vegetative stage, and in Co 18 and W 1263 at both vegetative and heading stages.

Among the breeding lines, selections from the cross Phalguna x TKM 6 (RP 2199) figured prominently. One of the selections from the cross Swarnadhan x Velluthachera (RP 2068-18-2-9) was also rated as promising. Several multiple-resistant lines have been developed from this cross and are currently being evaluated against stem borer.

Table 3. Promising entries identified against stem borer under AICRIP 1983-1986.

Entry	No. of years with overall promising[1] reaction at	
	Vegetative stage	Heading stage
Manoharsali	1	3
Co 18	2	1
W 1263	1	1
RYT 2908	1	-
ARC 6044	1	-
ARC 5500	-	1
ARC 6215	-	1
RP2199-38-49-56-2	1	1
RP 2199-76-42-8	1	1
RP 2199-115-2	1	1
RP 2199-201-221	1	1
RP 2199-84-2	3	-
RP 2068-18-2-9	-	2

1. The test entry was considered promising if it had less than 20% deadhearts at vegetative stage or less than 10% white earheads at heading stage at most of the test locations.

Inheritance of Resistance

Inheritance of resistance to yellow stem borer in the cross Phalguna/TKM 6 has been studied by Prasad et al. (1984). On the basis of damage at heading stage, resistance to stem borer was observed to be governed by 3 dominant genes and 1 dominant inhibitory gene, resulting in a ratio of 27:229 (tolerant:susceptible) progenies in F2 generation. Furthermore, based on joint segregation, linkage was observed between one of the genes governing stem borer resistance and semi-dwarf habit, and also between a resistance gene and flowering duration gene.

Role of Resistant Varieties in IPM

Although no variety with a high degree of resistance to stem borer damage has been developed, earlier breeding programs involving TKM 6 as donor parent have produced several moderately resistant cultivars, including Sasyasree. Under AICRIP multilocational pest management trials, the role of such resistant varieties in stem borer management has been demonstrated. At selected 'hot spot'locations, use of moderately resistant varieties such as IET 2815(Sasyasree),IET2812,IET3116,andIET3127 could reduce pest incidence. Pest damage in moderately resistant varieties under no protection was lower than in the susceptible control variety under pest management employing need-based protection (Table 4). Moreover, cultivation of moderately resistant varieties coupled with need-based application of pesticides (pest management) increased grain yield.

Table 4. Stem borer incidence and grain yield recorded in moderately resistant and susceptible varieties in Pest Management Trial 1984-1986.

Variety	Protection level	Damage at: Vegatative stage (% DH) 1984 (3)[1]	1985 (2)	1986 (3)	Mean	Heading stage (% WE) 1984 (3)	1985 (2)	1986 (3)	Mean	Grain yield ($t\ ha^{-1}$) 1984 (3)	1985 (2)	1986 (3)	Mean
IET 3116 (Moderately resistant)	PM[2]	5.3	5.7	6.8	5.9	3.6	3.1	9.7	5.5	4.52	4.67	3.30	4.17
	NM[3]	7.9	6.5	9.7	8.0	5.0	4.5	13.7	7.7	3.87	4.04	2.68	3.53
IET 3127 (Moderately resistant)	PM	4.6	4.7	6.3	5.2	2.8	5.7	11.0	6.5	4.43	4.62	3.32	4.12
	NM	8.1	8.0	9.6	8.0	4.6	6.3	9.4	6.8	3.86	3.97	2.49	3.44
IET 2881 (Susceptible)	PM	8.9	7.5	14.0	10.1	6.0	10.4	16.2	10.7	4.15	4.17	2.57	3.63
	NM	13.4	17.2	21.7	17.4	10.4	16.8	26.0	17.7	3.50	3.28	1.97	2.92

1. Figures in parentheses are number of test locations considered.
2. PM = Pest Management through need-based pest control.
3. NM = No management of insect pests.

Discussion and Conclusions

Varietal differences in degree of susceptibility to stem borers have been reported from India as early as 1937. More systematic field evaluation at CRRI during the 1950s led to identification of a number of moderately resistant donors including TKM 6 and MTU 15 (Israel 1967). Extensive varietal evaluation programs under AICRIP during the 1960s and 1970s identified several Assam Rice Collections (ARC) accessions with varying levels of resistance (Shastry et al. 1971). Though consistency in performance of donors like TKM 6 and W 1263 was evident even in recent evaluations reported in this paper, none of the rice germplasm screened so far has displayed a high level of resistance. New donors reported here such as Manoharsali, ARC 5500 and others may serve to supplement future breeding programs.

Most varietal screening is reported from field studies under natural level of stem borer infestation. Such studies have the obvious limitations of nonuniform pest pressure over time and space. This is further complicated by the prevalence of different complexes of stem borer species at test sites. Differential reaction of varieties against different species are apparent. For instance, during the 1984 testing, RYT 2908 registered low dead heart damage at 5 test locations but registered the highest damage among test entries at Almora where the pink stem borer *S. inferens* predominated (AICRIP 1984). Likewise, differential response of varieties and damage at vegetative and heading stage is well-documented. Though attempts have been made to study the genetics of stem borer resistance (Koshairy et al. 1957, and Dutt et al. 1980), no specific genes conferring resistance have been identified. Thus, it is not clearly known if different moderately resistant donors possess the same set of genes or if there is any consistency in the makeup of genes governing resistance at different stages of plant growth. Nevertheless, efforts are being made to accumulate genes from different moderately resistant donors to develop varieties with higher levels of resistance than presently available (Choudhary et al. 1984).

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Breeding for Resistance to Stem Borer (*Chilo partellus* Swinhoe) in Sorghum

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Abstract

Stem borer (Chilo partellus *Swinhoe) is the most important pest of sorghum [*Sorghum bicolor *(L.) Moench]. Progress has been made in developing borer-resistant breeding lines with moderate yield and acceptable grain quality. Sorghum variety, ICSV 700, has high levels of stem borer resistance across several seasons and locations. Borer resistance is a quantitatively inherited trait governed by additive and nonadditive genes. Epistatic gene effects are more pronounced under artificial borer infestation. Cytoplasmic effects appear to be present.*

Résumé

Sélection de sorghos résistants aux foreurs des tiges : Le foreur des tiges (*Chilo partellus*) est le plus important ravageur du sorgho (*Sorghum bicolor*). On a fait des progrès dans la création de lignées en sélection résistantes au foreur ayant un rendement moyen et une qualité de grain acceptable. La variété ICSV 700 a montré de hauts niveaux de résistance au foreur lors de plusieurs saisons de cultures et sur plusieurs sites. La résistance aux foreurs des tiges est un caractère quantitatif contrôlé par des gènes additifs et non additifs. Les effets de gènes épistatiques sont plus marqués en infestation artificielle. Des effets cytoplasmiques seraient également présents.

Introduction

Sorghum grain yields are generally low (500-800 kg ha^{-1}) under farmers' conditions in the tropical world. One of the reasons for low yields is crop damage by insect pests. Among the many insect pests which attack sorghum, stem borers constitute the most widely distributed and serious group throughout the world (Young and Teetes 1977, and Seshu Reddy and Davies 1979b). Yield losses due to stem borer can be quite high (80%) in tropical sorghums. These insects are internal feeders, not much affected by predators and parasites, unfavorable environmental conditions, or insecticides. Host-plant resistance appears to be an economic, efficient, and a long-term solution to manage stem borers either alone or in combination with other methods of control. Research on host-plant resistance to sorghum stem borers has been done primarily with the spotted stem borer, *C. partellus.* In this paper, we review the work done on breeding for resistance to the spotted stem borer.

Screening Techniques

Development of an effective and reliable screening technique that ensures a uniform and desired level of

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insect pressure at the most susceptible stage of the crop is the backbone of a host-plant resistance breeding program. These requirements can be met either by selecting a location where the pest occurs regularly with adequate severity (hot-spot location) or by testing plant material under artificial infestation with laboratory reared insects. Other agronomic practices can also be used to increase the insect infestation such as planting time, use of diapausing insect population, trap crops, fertilization, and irrigation.

A three-step screening methodology was adopted for stem borer resistance testing in the All India Coordinated Sorghum Improvement Project (AICSIP) (Pradhan et al. 1971). The first step was a general screening carried out in single-row plots under natural infestation. Selected materials were then entered in multi-row replicated trials under natural infestation. The third step was confirmation of resistance in replicated trials under artificial infestation. ICRISAT employs a similar methodology (Fig.1) with some modification, and has worked with heavy natural infestation at Hisar and artificial infestation at ICRISAT Center.

Screening at a hot-spot location requires basic knowledge of insect population dynamics so that planting time can be adjusted to ensure that the susceptible stage of the crop coincides with the peak activity period of the insect. For instance, at Hisar, severe borer infestation has been recorded for 10 years (1977-87) on sorghum planted during the first fortnight of July (10-15 Jul). Early in the project

Table 1. Testing locations for stem borer resistance in AICSIP, 1977-86.[1]

	Leaf injury		Stem tunneling	
Location	Years tested	Effective years	Years tested	Effective years
Delhi	8	4	10	6
Indore	7	4	10	1
Udaipur	6	0	9	4
Navsari	5	4	6	0
Akola	6	2	9	7
Hyderabad	4	0	5	2
Dharwad	6	1	9	5
Coimbatore	4	0	4	3
Rahuri	5	2	6	0
Parbhani	1	0	7	2

1. Effective screening implies a minimum score of 5 for leaf injury (1-9 scale) and 25% tunneling on the susceptible genotype.
Source: AICIP 1977-86.

Table 2. Years of effective screening for stem borer resistance in AICSIP trials 1977-86.[1]

	Leaf injury		Stem tunneling	
Year	Locations tested	Effective locations	Locations tested	Effective locations
1977	-	-	8	1
1978	7	2	5	1
1979	7	4	8	5
1980	6	3	9	6
1981	6	4	9	3
1982	9	4	10	5
1983	5	0	7	1
1984	-	-	6	1
1985	4	0	7	1
1986	9	0	9	5

1. Effective screening implies a minimum score of 5 for leaf injury (1 9 scale) and 25% tunneling on the susceptible genotype.
Source: AICSIP 1977- 86.

AICSIP concentrated testing for stem borer resistance at Delhi, Udaipur, and Indore, where natural stem borer incidence was high. Additional test locations have been added in recent years to record data on stem borer infestation on the most susceptible sorghum genotype (Tables 1 and 2). The data indicate that in any year, sufficient infestation did not occur at all locations. In 4 out of 7 years, locations were less than 50% effective in terms of leaf injury (score of 5 on a 1-9 scale), and in 7 out of 9 years, incidence of stem tunneling was insufficient at all locations. This indicates that the pest attack was often too low at some of the testing locations and/ or the susceptible stage of the crop did not synchronize with the peak activity period of the insect.

Screening sorghum under artificial infestation has been accomplished by many researchers in India using laboratory reared insects. Stem borers have been reared both on natural food (Singh et al. 1983) and on synthetic diets (Chatterji et al. 1968, Dang et al. 1970, Siddiqui et al. 1977, and Seshu Reddy and Davies 1979b). In AICSIP, laboratory reared insects have either been released as first-instar larvae (Singh et al. 1983) or as blackhead egg masses in the leaf whorls (Jotwani 1978).

ICRISAT Center's artificial rearing laboratory supports the screening of 2-3 ha of sorghum each season by raising enough first-instar larvae to provide an infestation rate of 5-7 insects per individual plant. Details of this rearing method, field infesta-

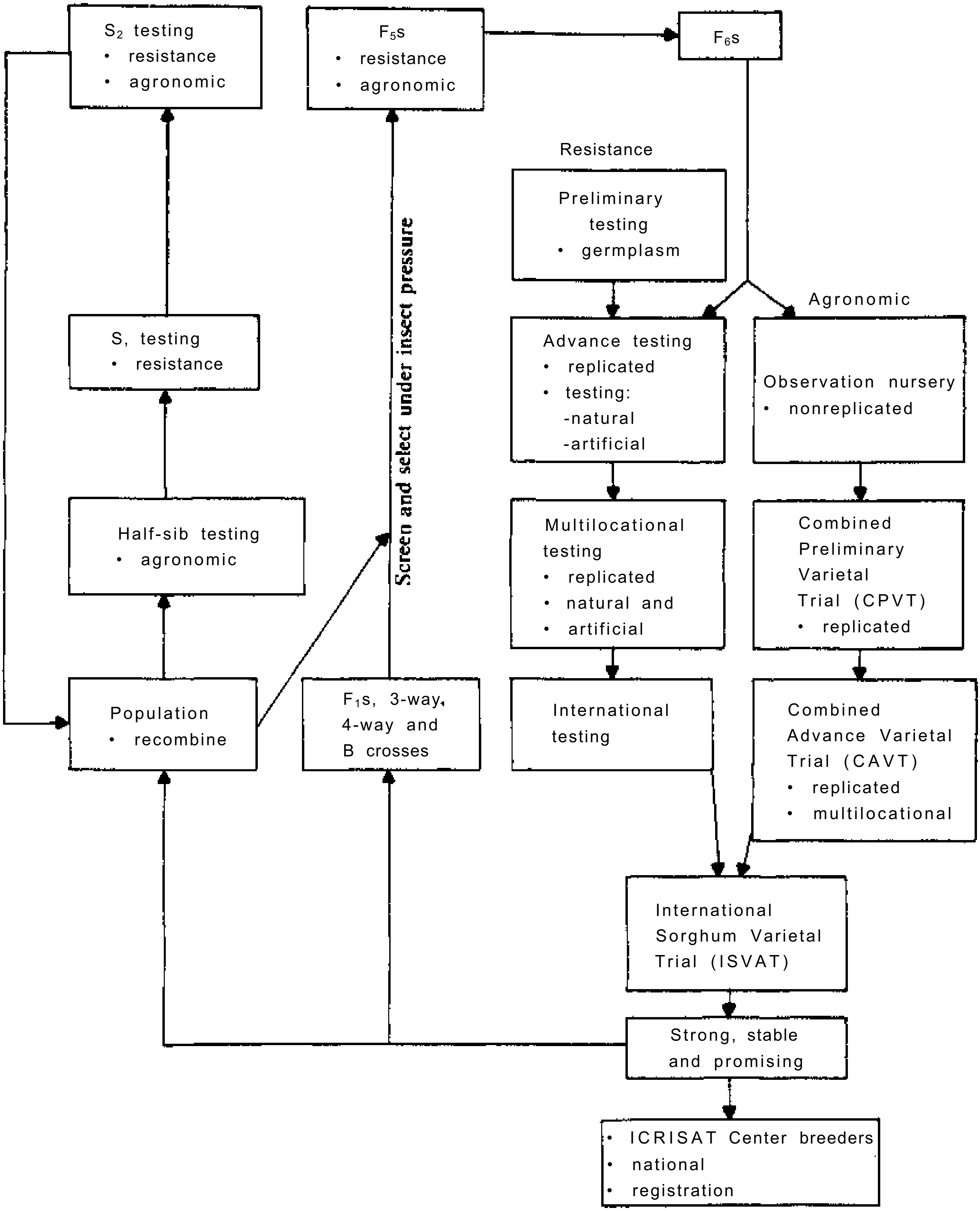

Figure 1. Screening and breeding for insect-pest resistance.

tion, and evaluation for stem borer resistance has been described by Taneja and Leuschner (1985).

Selection Criteria

Symptoms of stem borer attack in sorghum are leaf injury, tunneling of stem and peduncle, and deadheart formation. Each of these symptoms is not necessarily related to grain yield loss. Although leaf injury is the first indication of borer attack, it has no clear relationship with yield loss (Singh et al. 1983). Leaf injury score varies over time because the plant recovers by producing new leaves. However, Singh and Sajjan (1982) observed a positive relationship between leaf injury score and grain yield loss in maize.

Stem tunneling by borers is also not related to grain yield reduction in sorghum (Singh et al. 1983, Pathak and Olela 1983, and Taneja and Leuschner 1985). Stem and peduncle damage can be critical, however, under two situations: (1) if tunneling results in breakage of stem or peduncle; and (2) if tunneling interferes with plant nutrient supplies by destroying the vascular system of the stalk. These two situations depend on the critical stage of the crop at time of infestation, and borer density.

The most critical damage by the stem borer, which results in significant grain yield loss and low plant stand, is the formation of deadhearts. Taneja and Leuschner (1985) observed highly significant and negative relationship between number of deadhearts and grain yield of sorghum (r = -0.9). Singh et al. (1968) indicated that as a parameter of stem borer attack, the percentage of deadheart was the most stable criterion for differentiating degrees of resistance.

Researchers argue strongly that resistance screening should be based mainly on deadhearts, while stem tunneling and leaf injury can be subsidiary criteria. In AICSIP the deadheart parameter was used as a prime criterion for the evaluation of sorghum material for stem borer resistance until 1969. Only leaf injury and stem tunneling are being used as selection criteria at the present time. At ICRISAT, evaluations are done on the basis of deadheart incidence, with leaf injury and stem tunneling as secondary criteria.

Identification of Resistant Sources

The earliest report on sorghum cultivars resistant to spotted stem borer (C. *partellus)* is by Trehan and Butani (1949). Pant et al. (1961) and Swarup and Chaugale (1962) reported certain sorghum varieties to be relatively less-damaged by the stem borer than others. A systematic screening of the world sorghum collection for resistance to stem borers was started in 1962, in India, under the cooperative efforts of the Accelerated Hybrid Sorghum Project, Indian Council of Agriculture and Research (ICAR), the Entomology Division of the Indian Agricultural Research Institute (IARI), and the Rockefeller Foundation (Singh et al. 1968, Pradhan et al. 1971, and Jotwani 1978). This work has been continued by AICSIP and ICRISAT.

General screening of sorghum germplasm for stem borer resistance was carried out under natural infestation at Delhi from 1964 to 1969. A total of 8557 lines were screened, and 1375 lines were selected for further testing (Table 3). Evaluation of these lines was done on the basis of deadheart formation.

Retesting of selected germplasm accessions was carried out at Delhi, Udaipur, and Pune during 1966-76 and a number of accessions were selected for confirmation of resistance (Table 4). The resistance in selected genotypes was confirmed by artificial infestation at Delhi, Udaipur, Indore, and Kanpur (Table 5).

At ICRISAT, stem borer resistance work began in 1979 using artificial infestation (Seshu Reddy and Davies 1979). Later on, testing of the material also began at Hisar under natural infestation. Out of nearly 16000 germplasm accessions tested over several seasons, 72 genotypes have been found to be resistant (Table 6). Most of these sources are of Indian origin; however, some genotypes are from

Table 3. Screening of sorghum germplasm for stem borer resistance under natural infestation.

Year	Accessions Screened	Accessions Selected	Selection criteria[1]	Incidence on susceptible control
1964	3492 }			
1965	461 }	507	DH	80% (32-100%)
1967	890 }	74	LI, ST	ST =58%
1968	2906	794	LI, DH, ST	DH=32% ST =30%
1969	808	0	LI, DH	

1. Selection criteria: LI = leaf injury, DH = deadhearts, ST = stem tunneling.

Source: Singh et al. 1968, and Pradhan et al. 1971.

Table 4. Screening of sorghum genotypes for stem borer resistance under natural infestation in replicated trials, AICSIP 1966-76

Year	Accessions		Selection criteria[1]	Incidence on susceptible control	Promising genotypes
	Screened	Selected			
1966	488	57	LI, DH, ST	-	IS Nos. 1034, 1099, 1151, 1499, 5479
1967	104	73	LI, DH, ST	DH-38% ST-50%	IS Nos. 1034, 1044, 1087, 1115, 1137, 1151 3950, 4522, 4569, 4776, 4912, 4994, 5030
1968	91	42	LI, DH, ST	DH-30% ST-28%	IS Nos. 1044, 5030 5606, 5615, 5656
1969	151	40	LI, ST	ST-72%	IS Nos. 1151,4246,4307, 4339, 4868, 4870, 5072, 5599, 5629, 5653, 5662
	100	16	LI, DH	DH-29%	IS Nos. 1005, 1019, 1509, 1522, 1594,4522, 4780, 4793, 4797, 4833, 4866, 4870, 4897, 4912, 5615, 5701
1973	28	13	LI, ST	ST-23%	JML-2, AKL-5, Gangapuri, NCL-3, PCL-3, Aispuri
1976	23	23	LI, ST	-	VZM-2B, P 151, SPV 61

1. Selection criteria: LI = leaf injury, DH = deadhearts, ST = stem tunneling.
Source: Singh et al. 1968, Pradhan et al. 1971, and Jotwani 1978.

East Germany, Nigeria, Pakistan, Sudan, Uganda, USA, Yemen Arab Republic, and Zimbabwe. Stability analysis, of 61 resistant genotypes tested over six seasons indicated that the most stable resistant lines were IS 5470, IS 5604, IS 8320, and IS 18573 (Taneja and Leuschner 1985).

Resistance Mechanisms and Associated Factors

Knowledge of resistance mechanisms and associated factors in donor parents is important in transferring resistance into elite cultivars. The role of various mechanisms and morphological and chemical factors has been emphasized by several workers. A detailed review of this has been covered by Taneja and Woodhead in their paper Mechanisms of Stem Borer Resistance in Sorghum (these proceedings).

Genetics of Resistance

Knowledge of genetics of resistance and tolerance is prerequisite to determining appropriate breeding methods to be used in developing insect-resistant cultivars. There is limited information available, however, on inheritance of resistance to sorghum stem borers. Resistance to spotted stem borer *C. partellus,* measured in terms of leaf feeding injury, percentage deadhearts, and stem tunneling is polygenic (Rana and Murty 1971, Kulkarni and Murty 1981, Pathak and Olela 1983, Pathak 1983, Rana et al. 1984, Hagi 1984, and Pathak 1985). Rana and Murty (1971) indicated that the inheritance patterns of primary (leaf injury) and secondary (stem tunneling) damage were different. Resistance to primary damage was predominantly controlled by additive and additive x additive gene effects while additive and nonadditive gene effects were important for secondary damage. Height and maturity traits were also found to be associated with different

Table 5. Confirmation of stem borer resistance in sorghum lines under artificial infestation, AICSIP 1966-1975.

Year	Number of lines		Selection criteria[1]	Incidence on susceptible control	Most promising lines
	Screened	Selected			
1966	5	5	DH	-	IS Nos. 1034, 1099, 1151, 1499,5479
1968	59	36	LI, DH, ST	DH- 18% ST- 34%	IS Nos. 1099, 1115, 1458,3967,4118,4283, 4316, 4522, 4651, 4776, 4780,4897,5115, 5469, 5613, 5656
	17	7	LI, DH, ST	DH- 9% ST- 33%	IS Nos. 1044, 1115, 1151, 4764, 4776, 4994, 5030
1969	20	6	LI, ST	ST-76%	IS Nos. 1056,4552,4651, 4747, 4782, 5470
1972	8	7	LI, ST	ST-87%	IS Nos. 4424, 4689, 4827, 4841,4875,4934,5031
1973	98	25	LI, ST	ST-65%	IS Nos. 2122, 4329, 4799, 5251,6046,6101,6119
1975	25	12	LI, ST	ST-37%	
	12	6	LI, ST		GIB, BP 53, Aispuri, Nag-B, SPV 16 and R 147B

1. Selection outline: LI = leaf injury, DH = deadhcarts, ST = stem tunneling.

Source: Pradhan et al. 1971; Jotwani 1978.

types of damage. In a diallel cross analysis in F_2 and F_3 generations, Kulkarniand Murty (1981) reported that resistance to percentage deadhearts is governed by both additive and nonadditive types of gene actions, but predominantly by additive genes. The general combining ability (GCA) effects over generations indicated that at least one parent should be a good combiner in breeding for stem borer resistance. In another diallel cross analysis, Pathak and Olela (1983) showed that resistance to deadhearts (prim-

Table 6. Sources of resistance to sorghum stem borer identified by ICRISAT, 1979-86.

Origin	IS Number
India	1044, 1082, 1119, 2195, 2205, 2375, 2376, 4273, 4546, 4637, 4756, 4757, 4776, 4881, 4981, 5075, 5253, 5429, 5469, 5470, 5480, 5538, 5566, 5571, 5585, 5604, 5619, 5622, 8320, 13100, 17742, 17745, 17747, 17750, 17948, 17966, 18333, 18366, 18662, 18677, 21969, 22039, 22091,22145,23411,
Nigeria	7224, 18573, 18577, 18578, 18579, 18580, 18584, 18585
USA	2122, 2123, 2146, 2168, 2269, 10711, 20643
Sudan	2263,2291,2309,2312,22507
Uganda	8811, 13674
E.Germany	24027
Ethiopia	18551
Pakistan	9608
YAR	23962
Zimbabwe	12308

Source: Taneja and Leuschner 1985.

ary damage) is governed predominantly by additive genes. They also found that inheritance patterns of primary and secondary damage are different. Both resistance and tolerance mechanisms for stem borer resistance exist in sorghum.

Hagi (1984) studied the genetics of resistance (percentage deadhearts) to spotted stem borer under natural and artificial infestations, and found different patterns of resistance under these two situations. Major gene effects (additive and dominant) were found to be contributing under natural infestations while epistatic effects (additive x additive, additive x dominant, and dominant x dominant) were predominantly contributing under artificial infestation, where the expression of major gene effects is masked. In turn, his studies indicated that the ovipositional nonpreference mechanism is controlled by major gene effects, while antibiosis is influenced by epistatic gene effects. The epistatic gene effects were found unstable over environments.

Pathak (1985) reported that susceptibility is dominant over resistance in susceptible x resistant (SxR) and susceptible x tolerant (SxT) crosses, while resistance was dominant over susceptibility in the tolerant x resistant (TxR) cross. Both resistance and tolerance mechanisms were found to be operating and independently inherited. Estimates of low heritability, genetic coefficient of variability, and expected genetic advance indicated the usefulness of recurrent selection to simultaneously improve the level of stem borer resistance, tolerance, and yield in sorghum.

Breeding for Resistance

Breeding for stem borer resistance started in 1966 in India, when a number of resistant parents were included in the breeding program (Pradhan et al. 1971). Since then a number of identified sources of resistance have been utilized by crossing them mostly with agronomically elite susceptible parents. A list of promising derivatives and their parents is given in Table 7. A borer-resistant parent, BP 53, has produced a number of promising derivatives, particularly when crossed with IS 2954. Other good resistant sources have been Aispuri, M 35-1 and Karad Local. Stem borer resistant sources have also been utilized in developing high-yielding varieties and hybrids in AICSIP (Table 8).

One of the objectives of the Stem Borer Resistance Program initiated at ICRISAT was to strengthen the sources of resistance by accumulating diverse genes from different sources. To meet this objective, a population breeding approach was chosen. A sorghum population resistant to shoot pests, (shoot fly and stem borer) has been developed using ms_3 and ms_7 male-sterility genes. So far, a total of 175 genotypes have been fed into this populations (85

Table 7. Most productive borer resistant sources and their promising derivatives.

Resistant source	Other parent	Promising derivatives
BP 53	IS 2954	Selection nos. 165, 169, 174, 177,300,364,384,434,446,468, D nos. 124, 167, 168, 172, 175, 244, 259, 350, 358, 365, 366, 367, 609, DU nos. 98, 135,245,293, P nos. 108, 151,235, U 376
	IS 84	Selection no. 602
	IS 3691	DU 291, U 369
	CK 60 B	E 302, U nos. 37, 218, 35, 373
	IS 3954	E 303
Aispuri	IS 3922	Selection nos. 829, 835, D 832
M 35-1	IS 539	DU 19
	IS 531	U 83
IS 4906	CK 60A	P 37
IS 5837	CK 60A	P 82
IS 10327	CK 60A	P 90

Source: AICSIP 1972-85.

Table 8. Stem borer resistant sources utilized in AICSIP.

Resistant source	Promising varieties/hybrids
Aispuri and its derivatives	CSV 5, SPV nos. 14, 58, 80, 96, 99, 101, 102, 104, 105, 107, 108, 110, 115, 168,265,270,271,374,378, 475, 513, 516, 716, 727, 743, 744, CSH 7R
IS 3541 (CS 3541)	CSV 4, SPV nos. 60, 104, 122, 126, 245, 292, 297, 303, 312, 346, 351,354,371,386,741
M 35-1 (IS 1054)	CSV 7R, SPV nos. 19, 270, 364, 440, 510, 727
GM 1-5	SPV nos. 9, 33, 34, 183, 268
Karad Local	CSV nos. 2, 6, SPV nos. 8, 13, 17
BP 53 (IS 1055)	CSV 3, 26, 70, 513, 688
PD 3-1	CSH 8R

Source: AICSIP 1975-86.

stem borer resistant sources and their derivatives, 76 shoot fly resistant sources and their derivatives, and 14 elite genotypes). After six cycles of random mating under borer-infested conditions, this population has shown good improvement for agronomic features and resistance. The shoot pests resistant population is being advanced by using (S_2) cyclic recurrent selection as outlined in Figure 2.

A comparison of 135 fertile derivatives (S_2) of the shoot pest population and 130 advanced progenies from pedigree breeding was made for stem borer resistance at ICRISAT Center under artificial infestation, and at Hisar under natural infestation, during the 1986 rainy season. In general, the population derivatives showed better levels of resistance under both types of infestation compared with progenies derived through pedigree breeding (Fig.3). The population derivatives showed a good level of borer resistance, 6%, compared with only 0.6% resistance of the pedigree progenies.

Transfer of resistance into improved genotypes, initiated through the pedigree breeding approach has utilized a number of resistant sources (Table 9). Most productive are IS 1082, IS 3962, IS 5604, and IS 5622. The most promising derivatives are ICSV

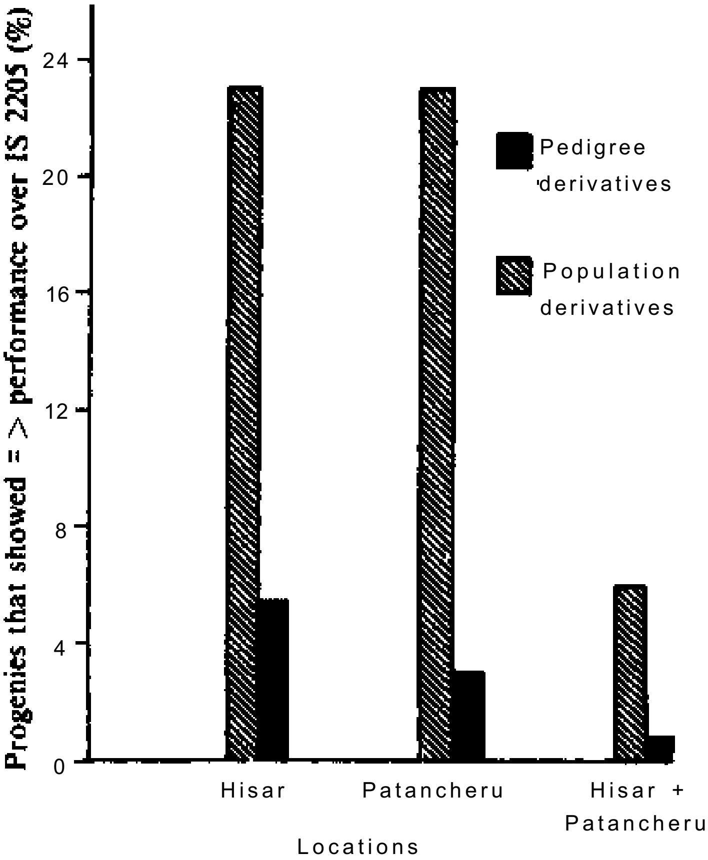

Figure 3. Performance of pedigree and population derivatives against stem borer.

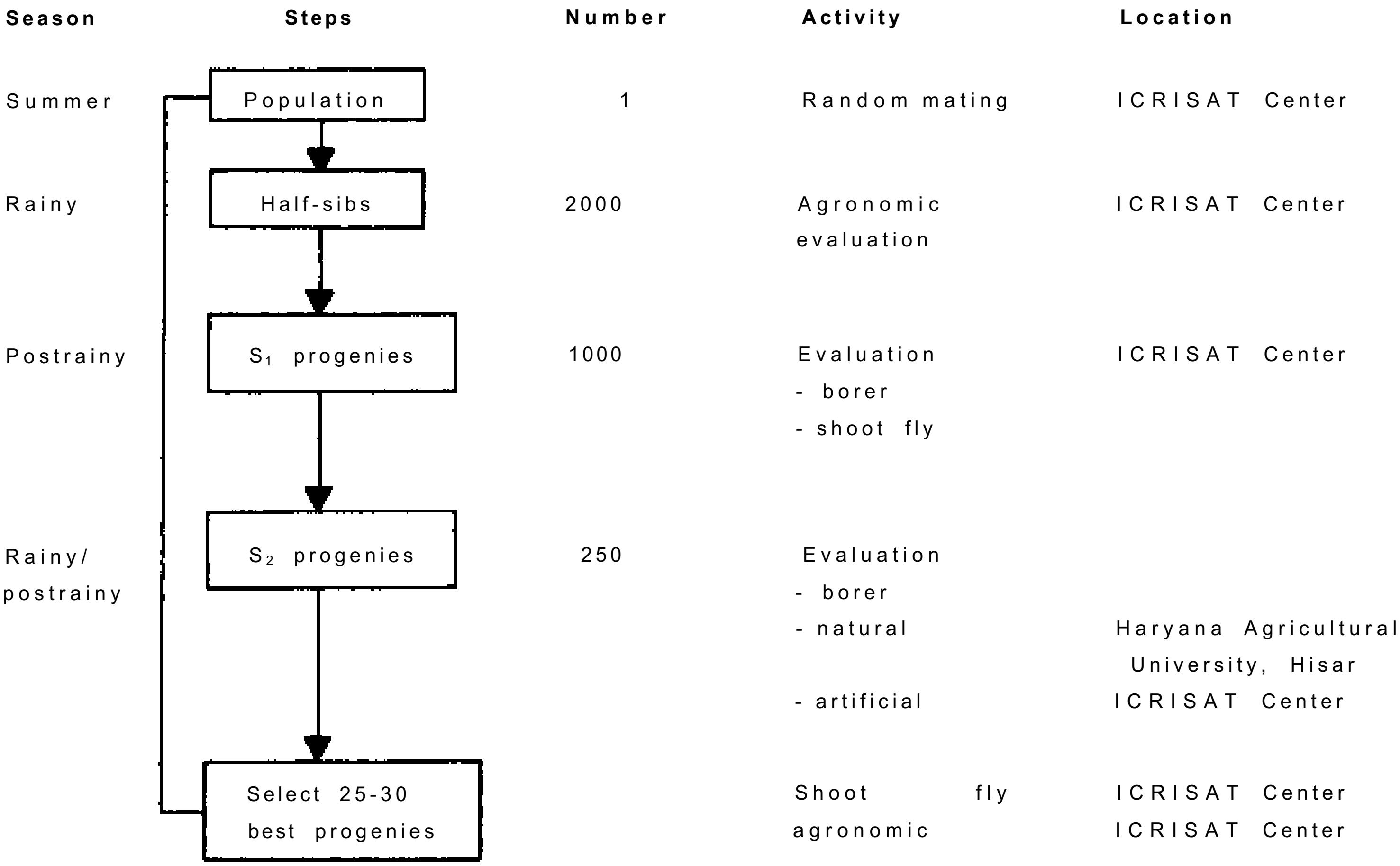

Figure 2. Scheme for recurrent selection.

Table 9. Stem borer resistant sources and their promising derivatives, utilized at ICRISAT Center.

Resistant source	Promising derivatives
IS 1082	PS 14413, PB 10791, PB 12446
IS 2312	PS 19338, PB 12693
IS 3962	PS 18601, PS 18822, PB 12611, PB 12631
IS 5604	PS 18527, PS 19336, PS 27623 PB 10365, PB 12040, PB 12497, PB 12687, PB 12689
IS 5622	PS 14454, PS 19295, PS 19663, PS 21113, PS 30768, PS 30769, PS 31376, PB 10337, PB 10445, PB 10446
IS 13681	PB 12049, PB 12050
Shoot pest population	PB 12339, PB 12342, PB 12346, PB 12380, PB 12387, PB 12413

700, ICSV 701, ICSV 825, ICSV 826, 1CSV 827, ICSV 828, and ICSV 829 (Table 10).

Experience over the years has shown that there is very little correlation between selections made for stem borer resistance under natural and artificial conditions. This may be due to the differential expression of resistance mechanisms in these two types of infestations. Some mechanism(s) may not be operating under both types of infestations. Similar observations were made by Haji (1984) in his genetic studies conducted in relation to natural and artificial infestations. This apparent dichotomy needs scrutiny, particularly as any correlation may influence future breeding strategies for borer resistance.

Table 10. Performance of improved lines for stem borer resistance.

Line	Resistance index[1]	
	Natural	Artificial
1CSV 700	0.50	1.250
ICSV 701	0.65	0.625
ICSV 825	1.05	1.320
ICSV 826	0.90	0.625
ICSV 827	0.13	1.380
ICSV 828	0.94	0.710
ICSV 829	0.96	0.700

1. Resistance index = $\frac{\text{\% of deadhearts in a particular line}}{\text{\% of deadhearts in resistant control (IS 2205)}}$

Conclusions and Recommendations

The effectiveness of a host-plant resistance breeding program largely depends on the development of a reliable screening technique, reliable criteria for measuring resistance, identification of stable sources of resistance, knowledge of the inheritance of resistance per se, the resistance mechanisms, and finally the selection of breeding procedures to incorporate resistance into agronomically superior backgrounds.

Although considerable work on host-plant resistance to stem borer has been accomplished in India and elsewhere, there is still a scope for further improvement. Intensified efforts are needed in the following areas:

- Natural borer infestations at specific locations should receive a thorough examination of population dynamics, planting time, use of overwintering population, fertilizers, and other factors affecting these populations.
- Feasibility of artificial infestation should be considered by national programs according to the facilities and support available.
- Determine breeding should be carried out under natural or artificial borer infestations, or under both types.
- Deadhearts should be given prime consideration as a selection criterion for resistant types. Stem tunneling and leaf injury should be used as secondary parameters.
- Tolerance should be considered as a factor in breeding for borer resistance.
- Cultivars with multiple resistance should be developed according to regional needs.
- More genetic information needs to be generated on individual resistance factors/mechanisms/resistance.
- Resistant parents need to be developed to use in the further development of resistant hybrids.

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Breeding Maize and Sorghum for Resistance to the European Corn Borer

W.D. Guthrie[1]

Abstract

Resistance in maize, Zea mays *L., to leaf feeding by first-generation European corn borers (ECB),* Ostrinia nubilalis *Hubner, is conditioned by at least eight genes. Resistance to sheath-collar feeding by second-generation ECB is conditioned by at least seven genes. Reciprocal translocation studies showed that at least 12 of the possible 20 chromosome arms, contributing a minimum of 13 genes, are in volved in resistance; only 2 or 3 of the 12 chromosome arms are in common for genes resistant to the two ECB generations. Thus, resistance to the ECB is conditioned by two different mechanisms. This number of genes rules out the possibility of using a backcross procedure to transfer resistance to susceptible maize genotypes. A recurrent selection breeding technique was used to develop genotypes of maize resistant to leaf feeding by first-generation ECB, resistant to sheath-collar feeding by second-generation ECB, and to develop genotypes with resistance for the whole life of the plant.*

Résumé

Sélection du maïs et du sorgho pour la résistance à Ostrinia nubilalis : *La résistance chez le maïs (*Zea mays*) à la consommation du feuillage par la première génération d'*Ostrinia nubilalis *est contrôlée par au moins huit gènes. La résistance à la consommation des gaines et du collet par la deuxième génération est gouvernée par au moins sept gènes. Des études sur les translocations réciproques ont révélé qu'au moins 12 des 20 bras des chromosomes possibles, contribuant à un minimum de 13 gènes, sont impliqués dans la résistance; seuls 2 ou 3 des 12 bras des chromosomes sont communs pour les gènes de résistance aux deux générations d'insectes. La résistance à* Ostrinia nubilalis *est donc déterminée par deux mécanismes différents. Ce nombre de gènes élimine la possibilité d'utiliser un rétrocroisement pour le transfert de la résistance aux génotypes sensibles de maïs. Une technique de sélection récurrente a été utilisée pour créer des génotypes ayant une résistance à la consommation du feuillage par la première génération et une résistance à la consommation des gaines et du collet par la deuxième génération d'une part, et des génotypes ayant une résistance qui persiste pendant toute la vie de la plante d'autre part.*

Introduction

A successful host-plant resistant project is dependent upon: (1) an efficient insect-rearing technique; (2) efficient artificial infestation of crop plants; (3) efficient evaluation of plants; (4) genetic techniques; and (5) plant breeding techniques. This approach has been employed by both the public and private sectors in the USA and approximately 10 other countries in breeding maize, *Zea mays* L., for resistance to the European corn borer (ECB), *Ostrinia nubilalis* Hubner.

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Egg Production

The use of wheat germ marked the advent of practical artificial diets for rearing plant-feeding Lepidoptera. This is the single most significant breakthrough in breeding maize for resistance to the ECB. In 1987, researchers in the private and public sectors in the USA and several foreign countries produced 70 million ECB egg masses (2 billion eggs) for host-plant resistance research. Using the meridic diet technique, seven times as many egg masses were produced in 1987 than were produced by the United States Department of Agriculture (10 million masses) over a 33-year period (1932-65) with the old technique (Guthrie 1987).

Plant Evaluation

In first-generation ECB resistance studies, maize and sorghum plants are infested with egg masses or larvae during the midwhorl stage of plant development. Relative degree of resistance (antibiosis) is measured by rating the leaf-feeding damage on plants (individual-plant or plot basis) on a scale of 1-9, where 1 = no damage to leaf tissue and 9 = extensive damage. Leaf-feeding damage ratings are made 3 weeks after egg hatch.

In second-generation ECB resistance studies, maize plants are infested with egg masses or larvae (sorghum plants are infested with egg masses) during anthesis. Antibiosis in maize is scored by rating the sheath-collar feeding damage on plants (plot basis) on a scale of 1-9, where 1 = no damage, and 9 = extensive damage. Sheath-collar feeding ratings are made 45-60 days after egg hatch. Genotypes with ratings of 7-9 are discarded. Cavity counts (cm of damage in stalks) may be used to detect differences among genotypes with ratings of 1-6. Damage (cm) in peduncles and heads may be used to detect differences among genotypes of sorghum.

Genotypes of maize are evaluated for tolerance by determining the percentage of broken stalks as an index of stalk strength, and by determining percentage of dropped ears as an index of shank strength (Guthrie and Barry In press).

Genetics and Breeding for Resistance to First-Generation ECB

Maize

During the period of egg deposition by first-generation ECB, maize is in the whorl stage of plant development. Most larvae feed on leaf tissue in the moist area deep in the whorl for several days after egg hatch. Most first-generation larval mortality occurs during the first few days after egg hatch. Resistance to first-generation ECB on maize is, therefore, leaf-feeding resistance; i.e., high antibiosis against first and second instars.

Breeding methods used to develop crop cultivars resistant to insects are determined by two factors: (1) mode of reproduction in the crop species; and (2) the kind of gene action that conditions resistance in the host-plant to the insect.

Many studies have been made to determine the genetic basis of resistance (Guthrie and Russell In press). Segregation of F_2 and backcross generations of a susceptible (M 14) x resistant (MSI) cross indicates that at least three gene pairs are involved in leaf-feeding resistance, with at least partial phenotypic dominance of susceptibility. In a B14 (susceptible) x N32 (resistant) cross, one or two genes for leaf-feeding resistance by first-generation borers were indicated on the basis of individual plant segregation in F_2 and in backcrosses. In another susceptible (WF9) x resistant (gl_7 V_{17}) cross, segregation of F_2 and backcross populations showed that resistance of gl_7 V_{17} was conditioned by a single dominant gene. The resistant gene was linked with gl_7 V_{17} genes of the resistant parent with crossover frequencies estimated at 31-37%. It was concluded from the ease of transferring resistance by backcrossing with selection in the improvement of inbred line Oh45 that leaf-feeding resistance to first-generation borers was simply inherited. But in a study of the use of test crosses in breeding for resistance, segregation in a 24-line synthetic cultivar, as measured by the net variance, diminished after each selfing, while a significant residue of segregation remained in the fifth selfed generation. If there was an average of one effectual heterozygous locus in the S_5, theoretically, there should have been 2^5 or at least 32 effectual heterozygous loci five generations back in the S_0.

To determine the type of gene action involved in resistance to leaf feeding by first-generation borers, F_2, F_3, and selfed backcross populations of C131A (resistant) x B37 (susceptible) were used along with individual F_2 plants of (CI 31A x B37) x CI 31 A, and individual F_2 plants of (CI 31A x B37) x B37. Most of the genetic variance was of the additive type, although a portion of the genetic variance was of the dominant type.

Reciprocal translocations were used in identifying chromosome arms involved in resistance to ECB.

The inbred C131A has genes for resistance to leaf feeding by first-generation borers on the short arms of chromosomes one, two, and four, and on the long arms of chromosomes four and six. Inbred B49 has genes for resistance on these chromosome arms (possibly allelic to those of C131A) plus an additional gene for resistance on the long arm of chromosome eight. Leaf-feeding resistance factors differentiating the inbred line A411 from the susceptible line A344 are associated with one gene on the 3L chromosome, one gene on the 4L chromosome, and probably another on the 5L chromosome.

An Ac-Ds mutable system (jumping genes) was evaluated for inducing resistance to leaf feeding by first-generation ECB in two susceptible inbred lines (Oh28 and WF9) of dent maize. No mutants were found among 40000 plants evaluated. We did not prove that this biotech technique will or will not cause mutations for corn borer resistance; perhaps a million, 2 million, or 10 million plants would have to be evaluated. We believe that the Ac-Ds mutable system, however, is not a practical tool for maize breeders because the maize genotypes being improved may be obsolete before a mutant can be found.

The development of genotypes resistant to the ECB has been in progress for more than 60 years. Resistance to leaf feeding by first-generation ECB has been easy to find, whereas frequency of genes in maize for resistance to sheath-collar feeding by second-generation borers is low.

Open-pollinated cultivars were the direct source material for most of the inbred lines developed from 1930-40. During the 1940s and 1950s, inbred lines with a satisfactory degree of resistance were extracted from special crosses (second-cycle breeding). During the 1960s-80s, a recurrent selection technique was used to improve resistance in breeding populations from which resistant lines may be developed.

In a study of S_1 lines recurrent selection for leaf-feeding resistance by first-generation ECB in five synthetic cultivars of maize, two cycles of selection were sufficient to shift the frequencies of resistant genes to a high level in all cultivars. Three cycles of selection produced essentially borer-resistant lines.

In Iowa, 34 of the 99 most widely used public inbred lines of maize rated highly resistant, resistant, or intermediate in resistance to leaf feeding (antibiosis) by first-generation ECB. In the United States in 1975, about 7.4 million ha of maize were planted to hybrids whose pedigrees contained at least one of the resistant or intermediate lines. Only one of the 99 inbreds (SC213) rated resistant to sheath-collar feeding (antibiosis) by second-generation ECB.

Sorghum

Most ECB larvae feed on leaf tissue in the moist area deep in the whorl of sorghum, *Sorghum bicolor* (L) Moench, for 9 days after egg hatch. Most first-generation ECB larval mortality occurs during the first few days after egg hatch. Resistance to first-generation ECB on sorghum, as in maize, is therefore leaf-feeding resistance, i.e., high antibiosis against first and second instars.

During the 1960s, several sorghum cutlivars were evaluated under a low level of artificial ECB infestation (75 eggs per plant). During 1981-83, 208 sorghum hybrids were evaluated under a high level of artificial ECB infestation (750 eggs per plant). All sorghum genotypes were resistant to leaf feeding by first-generation ECB. The leaves on sorghum had pinholes, indicating that some larvae fed for only a short time on leaf tissue.

Because all sorghum genotypes are resistant to leaf feeding by first-generation ECB, the type of gene action and number of genes conditioning resistance are impossible to determine.

Genetics and Breeding for Resistance to Second Generation ECB

Maize

During the period of egg deposition by second-generation ECB, maize is in various stages of anthesis. Most larvae feed on sheath-collar tissue for several days after egg hatch. Resistance in maize, therefore, is resistance to sheath-collar feeding.

A generation-mean analysis was used to determine the genetic basis of sheath-collar feeding resistance by second-generation borers. Nine populations were studied: P_1, P_2, F_1, F_2, F_3, BC_1, BC_2, and selfed progenies of both backcrosses. The data indicated no simple genetic basis of resistance and suggested that high resistance to a second-generation infestation may be the result of the cumulative effect of an unknown number of loci. Additive genetic effects were predominant in conditioning resistance, but dominance was significant in all crosses.

Inbred B52 (highly resistant to sheath-collar feeding by second-generation borers) contains a gene or genes on the long arms of chromosomes one, two, four, and eight and on the short arms of chromosomes one, three, and five. The frequency of genes for resistance to sheath-collar feeding by second-generation ECB is very low. Only one inbred line, B52, and three maize composite populations have a good degree of resistance.

Sorghum

During the period of egg deposition by second-generation ECB, sorghum is in various stages of anthesis. Most larvae feed on sheath-collar tissue for 35 days after egg hatch. Resistance in sorghum as in maize, therefore, is resistance to sheath-collar feeding. Sorghum genotypes vary in degree of resistance-susceptibility when an infestation occurs during anthesis. Some genotypes are highly susceptible, however, ECB larvae rarely enter sorghum stalks below the peduncle, so only peduncles and heads are damaged. In constrast, on susceptible genotypes of maize infested during anthesis, ECB larvae tunnel throughout the whole plant.

The genetic basis of sheath-collar feeding resistance in sorghum is not known. A full set of trisomies is available for locating chromosome arms involved in insect resistance, but the trisomic genetic stocks are difficult to maintain. A full set of reciprocal translocations (20 are needed) is not yet available in sorghum for determining the number of genes conditioning resistance to second-generation ECB. Three cycles of S_1 line recurrent selection in two sorghum populations increased resistance to second-generation borers. As in maize, polygenes probably condition resistance to second-generation ECB in sorghum.

Combining Resistance in Maize to First- and Second-Generation ECB

Population improvement programs are needed to develop genotypes resistant throughout the life of the maize plant because genotypes of maize, resistant to first-generation ECB, are usually susceptible to second-generation ECB.

Results from reciprocal translocation studies showed that at least 12 of the possible 20 chromosome arms, contributing a minimum of 13 genes, are involved in resistance to ECB. This number of genes rules out the possibility of using a backcross procedure to transfer resistance to susceptible maize genotypes. In many efforts to breed for resistance to leaf feeding by first-generation ECB, the backcross method was not successful when the recurrent parent was susceptible. The desired genotype could not be identified in the segregating generations. When more than two backcrosses were used, the needed level of resistance was lost. The level of resistance could be increased, however, by intermating among resistant plants in progeny of the first or second backcross.

Reciprocal translocation studies also showed that only 3 of the 12 chromosome arms are in common for genes resistant to the two ECB generations. Evaluation of S_1 lines showed near-zero correlation between the two ECB generations for resistance. Thus, resistance to ECB is conditioned by two different mechanisms.

Ten inbred lines were selected to develop a synthetic cultivar, designated BS9, specifically for S_1 recurrent selection for ECB resistance throughout the whole life of the plant. The 10 lines were: B49, B50, B52, B54, B55, B57, B68, C131A, Mol7, and SD10. These lines vary in their resistance to the two generations of ECB.

The objective in the BS9 improvement program was to evaluate 300 S, lines in each cycle (ca 10% of the best S_1 were recombined to start the next cycle) in three replications using separate experiments for the two generations under heavy artificial infestation.

When BS9(CB)C4 (four cycles of recurrent selection) was released to the hybrid seed industry in 1982 it marked a significant event in host-plant resistance investigations. It was the first Corn Belt (midwestern United States) synthetic specifically developed and released with resistance to ECB for the whole life of the plant. To determine the efficacy of S, recurrent selection for resistance to the two generations of ECB, the base population (CO) and four succeeding cycles (C1, C2, C3,and C4) of selection in BS9 were evaluated both for ECB resistance and correlated effects of agronomic traits. Each population (CO, CI, C2, C3, C4) was crossed with four Corn Belt inbreds (test cross parents) selected on the basis of their reactions to the two generations of ECB: B73 is susceptible to both generations; B75 is highly resistant to first and susceptible to second generations, B52 has intermediate resistance to first generation, and is highly resistant to second generation; and B86 is highly resistant to both generations.

Significant increases were found from BS9CO to BS9 (CB) C4 for resistance to first generation (leaf feeding), second generation (sheath-collar feeding), and stalk tunneling (cavity counts). First-generation leaf-feeding damage decreased from 3.6 in CO to 2.7

in C4 for cycles and from 3.9 in CO to 3.2 in C4, for cycles in test crosses. Second-generation sheath-collar feeding damage decreased from 6.4 in CO to 4.4 in C4 for cycles and from 5.6 in CO to 4.7 in C4, for cycles in test crosses. Second-generation damage in stalks (one cavity = 2.5 cm) decreased from 8.4 in CO to 3.3 in C4 for cycles and from 7.4 in CO to 4.9 in C4, for cycles in test crosses.

The increase in resistance in populations of BS9 reduced yield losses under artificial infestations of ECB, but the reduction was not sufficient to compensate for the loss in yield potential that occurred as a correlated effect from selection for ECB resistance. Reduction in the grain yield from BS9CO to BS9(CB)C4 under no artificial infestation was estimated to be 8.4% caused by changes in gene frequency due to selection and 18.8% caused by inbreeding depression due to drift. Most of the yield reduction, therefore, was caused by a random fixation of heterozygous loci, and the yield reduction may have been increased because of linkages to alleles of other traits under direct and indirect selection.

S, recurrent selection, therefore, was effective in increasing resistance throughout the life of the maize plant, but unfavorable responses in other agronomic traits, particularly in grain yield, suggest that the selection criteria for ECB resistance should include yield.

Because of limitations of resources for replicated yield trials and the importance of population size to reduce drift, an S_1 recurrent selection program would be the most desirable method to implement. Although this would require an extra year in temperate zones, selection can be conducted in two seasons. The S_1 lines could be evaluated for first- and second-generation ECB resistance, anthesis date, and plant height in one or two replications to eliminate the most undesirable lines. These traits could then be evaluated again in a smaller population of S_2 lines, in addition to evaluations for yield in replicated trials.

Inbred B86 was developed by selecting and self-pollinating through several generations in progeny of a single cross, B52 x Oh43, under high artificial infestations of both generations of ECB. The inbred contributes resistance to first-generation ECB (from the Oh43 parent) and resistance to second-generation ECB (from the B52 parent) in single-cross hybrids. B86 was the first inbred of Corn Belt origin known to combine into one genotype good resistance to the insect for the life of the plant. Recently, two other publicly released inbreds, SC213 and DE811, have displayed resistance to both ECB generations.

Chemical Basis of ECB Resistance

Maize

DIMBOA (2,4-dihydroxy-7- methoxy- 1,4- benzoxazin-3-one) is a chemical factor present in resistant genotypes of maize in the whorl stage of development. A simple inbreeding and selection technique for DIMBOA (in a cross of a susceptible and resistant inbred line) and a recurrent selection technique can be used to increase levels of DIMBOA for resistance to leaf feeding by first-generation ECB. Selection only on the basis of DIMBOA, however, may cause the eventual loss of other ECB resistance factors in maize breeding populations. Furthermore, DIMBOA is not a factor in resistance of genotypes of maize to second-generation ECB because sheath-collar tissue contains very little DIMBOA.

Sorghum

DIMBOA is not a chemical factor in the resistance to leaf feeding by first-generation ECB. Research in 1949 implicated cyanogenetic (HCN) as a resistance factor. If HCN is, however, a resistance factor, it is effective at very low concentrations because genotypes of sorghum containing low levels of HCN were as resistant as genotypes containing high levels of HCN.

Discussion and Conclusions

A host-plant resistance project is of value even if it only prevents the release of extremely susceptible germplasm. For example, in our 14 000-20 000-plot nursery (Corn Insect Research Unit), each year a few lines are so highly susceptible to ECB that the insect kills every plant. This type of material is culled immediately.

Hopefully, some of the genetic engineering techniques will be useful in breeding maize for resistance to insects. Improvement in crops with multiple gene traits, however, is a building process based on stepwise accumulation of genes with favorable additive effects. At present, the only known way to accumulate favorable genes for multiple gene traits is by selecting over several sexual generations involving genetic recombination. In sexually produced crops, the most efficient breeding methods to accumulate favorable genes will necessarily play the largest role in plant breeding.

Resistance to leaf feeding by first-generation ECB is conditioned by at least eight genes, and resistance to sheath-collar feeding by second-generation ECB is conditioned by at least seven genes. Recurrent selection breeding methodology has been successful in developing genotypes of maize with resistance to both generations of borers. It is not known if genetic engineering techniques will be as successful or faster than recurrent selection in breeding genotypes of maize resistant to insects.

Genetic engineering technology may be used to insert a genetically engineered *Bacillus thuringiensis (B.t.)* toxin gene into the plant itself, making the plant inherently resistant to insects. The level of gene expression must be high enough so that an insect feeding on the plant tissue consumes a lethal dose of the toxin before the plant incurs unacceptable levels of damage (Kirschbaum 1985).

McGaughey (1985) reported that, in tests with *B. thuringiensis* for the control of the Indianmeal moth, *Plodia interpunctella* (Hubner), two generations of exposure resulted in 30-fold resistance and that 15 generations of exposure resulted in 100-fold resistance of the insect to the pathogen. At present, it is not known if insects feeding on *B.t.* toxin-transformed plants will also develop resistance. It is known that genotypes of maize developed (by orthodox breeding methodology) for resistance to insects such as the ECB, have not developed insect biotypes that can overcome the resistance (probably because resistance is multigenic).

Assuming that a *B.t.* toxin gene can be inserted into maize plants rendering susceptible genotypes resistant to insects, many questions will have to be answered before the technique can be used in breeding maize for resistance to insects. For example, will the *B.t* toxin gene express itself in all plant parts? Whorl leaves contain factors conditioning resistance to leaf feeding by first-generation ECB. Sheath-collar tissue contains factors conditioning resistance to second-generation ECB. The DIMBOA gene or genes are expressed at a high level in midwhorl leaves of some genotypes of maize but at a very low level in sheath-collar tissue. Thus, DIMBOA is a chemical factor conditioning resistance to leaf feeding by first-generation ECB, but is not a factor in conditioning resistance to sheath-collar feeding by second-generaton ECB. For the *B. t.* toxin gene to be effective throughout the life of the plant, it will have to be expressed in several plant parts. Will maize insects feeding on *B.t.* toxin-transformed plants develop resistance to the *B.t.* toxin? Will single-cross hybrids be resistant if only one inbred line contains the *B.t.* toxin gene, or will both inbreds have to contain the gene?

Endophytes (microorganisms that live within a plant) may be useful in transporting the *B. t.* toxin to all plant parts. For example, Crops Genetics International Corporation has used biotechnology to modify the genetics of selected endophytes to produce biological crop protectants and growth enhancers. Tools of biotechnology include transformation (the process of introducing foreign DNA into an organism), recombinant DNA (new sequences of DNA formed by chemically recombining different segments of DNA), protoplast fusion (formation of a hybrid cell by joining two different cells from which the cell walls have been removed), and mutagenesis (the deliberate creation, utilizing physical, chemical, or biological agents of a mutant). The company expects to use recombinant DNA and mutagenesis for its crop protectant and growth enhancer products. Recombinant DNA technology requires that the company develop genetic transformation systems, a range of promoters (a DNA sequence that controls gene expression), and an array of appropriate vectors (the agent used to carry new DNA into a cell) for its endophytes and insert bacterial genes into the endophytes. The company has discovered an endophyte for maize, has refined recombinant DNA tools, and has acquired a gene producing a toxin active against the ECB. The insecticide gene is from a strain of *B. thuringiensis.* Molecular biologists have successfully engineered the *B.t.* gene into a nonendophytic bacterium and have demonstrated activity against the ECB. They are evaluating a range of promoters isolated from the maize endophyte for ability to drive the expression of the *B. t.* gene. They have inserted the *B. t.* gene into the endophyte and are currently evaluating the engineered bacteria for insecticidal output, genetic stability, and levels of colonization in laboratory and greenhouse trials. In summary, Crop Genetics International Corporation is developing a family of genetically engineered microbial pesticides, which can be inoculated into seeds and plants. These pesticide-producing microorganisms are designed to reside and function in a plant's vascular system and provide benefits for the life of the plant. Because the endophytic delivery system functions internally, the plant will protect the products from outside environmental forces that degrade externally applied biologicals and chemicals. The system should be cost effective because single application of minute dosages are anticipated to achieve and sustain potency for the life of the plant (Anonymous 1987).

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Discussion

Vidyabhushnam: What is the nature of inheritance of resistance to rice stem borer?

Kalode: In one of the crosses studied in rice by Prasad et al. in 1984, Phalguna x T K M 6, resistance is governed by dominant genes and 1 dominant inhibitory gene at heading stage.

Vidyabhushnam: While screening the breeding material for stem borer, what precautions are taken to control shoot fly? If the screening is done under conditions free of shoot fly, the chances of natural infestation by stem borer are also likely to be low. It would be desirable to have an approach combining the two pests together.

Agrawal: Shoot fly incidence is avoided by adjusting sowing dates. Regarding screening under natural infestation at Hisar, planting in the first fortnight of July resulted in very little shoot fly incidence. Screening under artificial infestation avoids the problem. Efforts are already being made to combine resistance to both shoot fly and stem borer.

Seshu Reddy: In answer to Dr Vidya Bhushanam's question, Dr Agrawal indicated IS 1082,2122,2312, 5604, and 5622 as materials contributing to stem borer resistance. All these entries are also resistant to sorghum shoot fly. I am happy that Drs Agrawal and Taneja have been trying to incorporate resistance sources of shoot fly and stem borer into high-yielding cultivars. In fact this is an excellent approach where two major pests have been considered.

Kaiser Jamil: Among the several strains of *Bacillus thruriongiensis,* which particular strain was utilized for incorporation into the seeds? How was this done?

Guthrie: These are trade secrets.

Seshu Reddy: In Africa, *Chilo, Busseola, Sesamia* and *Eldana* have all been found feeding on the grains. Does the corn borer bore into maize cobs?

Guthrie: Yes, the corn borer bores into maize cobs.

Mukuru: Dr Guthrie, you indicated in your presentation that there is resistance to first generation ECB in hybrids grown in the USA, but not to second generatione ECB. You also indicated that by using recurrent selection you have been able to increase resistance to both first and second generation ECB. Why is it then that second generation resistance has not been incorporated into commercial hybrids in the USA using recurrent selection.

Guthrie: We have recently received genotypes with resistance to both borer generations, so we have not had enough time to get these genotypes into hybrids.

Dakouo Dona: A lot of studies are undertaken on *C. partellus* at ICRISAT and at ICIPE. Why are similar studies not done on *B. fusca,* the main stem borer in Africa?

Seshu Reddy: Some work on the resistance of sorghum to *B. fusca* is being done at ICIPE under natural infestation. Investigations under artificial infestation are hindered because of lack of adequate techniques for the mass rearing of *B. fusca.*

Lavigne: If resistant hybrids of corn are so widely planted in the USA and give such good control of the first brood of ECB, why is the second brood infestation such a problem? This question relates to areas of Africa where sorghum is double-cropped. If we control the first generation with resistant lines, will we still have a problem with the second generation of stem borers?

Guthrie: The biological capacity of the ECB is great. A large second generation can develop from a small first generation population if climatic conditions are favorable.

Lukefahr: In hot-spot evaluation tests, what percentage of the time do you obtain results that are not comparable to artificial infestation? Also, how are hot spots selected?

Taneja: There is at least 50% correspondence between the results obtained at hot spots and under artificial infestations. Hot spots are selected on the basis of severity and regularity of the pest incidence at a particular location.

Plenary Session

Recommendations

In accordance with the objectives of the workshop participants were divided into two groups to deliberate on issues arising from presentations and discussions and to draw-up recommendations. These recommendations were presented at a plenary session during which each point was discussed, modified where necessary, and then approved. The recommendations are presented under two major sections: Biology and Control; and Host plant Resistance and Breeding for Resistance.

Biology and Control

Pest surveys

The need for surveys of sorghum stem borers on farmers' fields was recognized. These will require careful planning to obtain essential information using standardized procedures that will allow repeatability and comparision of data across locations. There is a need for: species identification; the farmers' perception of infestation levels, and losses; and identification of control measures employed in different countries. The need for logistic support with transport and other facilities in some areas was noted.

Diagnostic Aids

Accurate identification of pest species is essential in surveys and other work, and it was suggested that illustrated diagnostic data sheets should be produced by the Commonwealth Institute of Entomology (CIE) for the main stem borer species.

Biology, Ecology, Physiology, and Behavior

It is recognized that much published and unpublished information is already available but there is a need to prepare critical reviews as a basis for further work. This would best be done by reviewing information that relates to each of the major species (*Chilo partellus, Busseola fusca, Sesamia calamistis, S. cretica, S. inferens, Eldana saccharina, Acigona ignefusalis,* and *Diatraea saccharalis).* Emphasis should be placed on factors affecting the distribution of pest species, behavioral studies of adults and larvae (including adult dispersal and ovipositional preferences), the physiology of diapause, and population dynamics. Preparation of reviews will indicate where further research is needed to provide additional information.

Yield Loss Assessment

Evidence on crop losses directly attributable to sorghum stem borers is conflicting. The assessment of losses is difficult especially on farmers' fields, but there are important indirect effects of borer attack through interactions with stress factors, especially drought and sorghum midge. There is a need to determine situations in which stem borers are restricting sorghum production now, and are likely to restrict it in the future.

Control Measures

Chemical Control. Chemical control will continue to be used in some circumstances but seems unlikely to be used extensively on sorghum by small-scale farmers. In India, some further research is needed on techniques of application and economic thresholds.

Biological Control. The importance of endemic complexes of predators, parasitoids and pathogens in limiting stem borer infestations is not fully understood. It was stressed that the beneficial effects of these complexes should not be lost. Conservation and augmentation of natural enemies merit further study and a better understanding of the role of pathogens is needed.

Cultural Methods. It was agreed that the choice and implementation of cultural methods of control depend on local circumstances and action must be taken at that level.

Host-plant Resistance and Breeding for Resistance

1. Host-plant resistance is a viable option to stem borer management. In addition to the development of resistant cultivars it will help in avoiding the release of super-susceptible cultivars.

2. Rearing procedures and facilities for *Chilo* are adequate at ICRISAT, and are in progress at regional centers but not in some of the national programs. Rearing facilities for other stem borer species should be initiated. Hotspots should be identified for screening under natural infestation.
3. Infestation procedures are adequately established for *Chilo*. Infestation should be done at 2 and 4 weeks after emergence. Correlations should be worked out between early and late infestations with regard to leaf feeding and deadheart formation.
4. Evaluation for stem borer resistance should be carried out for the following parameters:

   - Leaf feeding at 7 days after artificial infestation and 3 and 6 weeks after emergence under natural infestation.
   - Deadheart counts should be taken 15 days after artificial infestation and 4 and 6 weeks after crop emergence under natural infestations.
   - Panicle damage should be evaluated at maturity.
   - Stem tunneling counts should be taken only in fodder sorghums and for economic threshold studies.

5. Biology and behavior of stem borers should be studied on resistant genotypes. Resistance mechanisms and associated factors should be worked out.
6. Genetics of resistance on each evaluating parameters should be reexamined through generation mean and diallel analysis, with emphasis on leaf feeding and dead hearts.
7. Utilize genetic information for deciding appropriate breeding schemes. Recurrent selection is presently being used in breeding for *Chilo* resistance at ICRISAT and also in combining *Chilo* resistance with resistance to other insect pests. This will help to accumulate resistant genes into common genetic background(s) for multiple resistance.
8. Screening of wild sorghums for stem borer resistance should be done to identify strong resistant sources.
9. The above recommendations are mainly for *Chilo partellus;* for other borer species they should be modified wherever necessary.
10. Since ICIPE is planning a stem borer workshop within the next three years, the progress made on stem borer research should be reviewed during that workshop.

Integrated Pest Management (IPM)

Stem borer research should have as its ultimate objective the development of IPM strategies for farming systems, talcing into account the farming communities in particular regions and subregions. Cultural methods and host plant resistance were recognized as the major viable components in IPM.

Training

Apart from general training at ICRISAT Center (IC) specific training at IC or in national programs should be organized in the form of training workshops. Such training should be conducted at regular intervals if they are to have long-term and sustained impact on national programs.

Group discussions on Resistance Screening Methodology and Yield Loss Assessments held at 1500-1630 on 20 Nov 1987

Following the recommendations in the plenary session, a special group meeting was held to discuss and streamline the procedures/methodologies to be used in resistance screening and yield loss assessments. The following is a summary of the discussions.

Screening Methodology

1. Damage rating for leaf injury should be scored from: 0 to 9
   0 = Immune
   1-2 = Highly resistant
   3-4 = Resistant
   5-6 = Intermediate
   7-9 = Susceptible
   Develop a diagramatic rating scale showing different scores for uniformity in evaluation. Prepare slides for use in workshops and seminars for national programs.
2. For evaluation under natural infestations, damage rating should be based on infested plants only.
3. Deadhearts should be considered a parameter as indicated in the recommendations i.e., deadheart

count 2 weeks after artificial infestation, and 4 and 6 weeks after crop emergence in case of natural infestation.

4. Panicle damage should be evaluated by conducting a series of experiments at various locations, with infestations at various crop growth stages (boot leaf, postboot leaf and panicle emergence). The following parameters should be noted: bored panicles and chaffy panicles/unproductive panicles.

Yield Loss Assessments

1. Pest surveys should be conducted in India for the major pests of sorghum. Their frequencies of occurrence and severity of attack should be monitored along geographical zones.
2. Yield loss assessment trials should be conducted at specific locations and the following methodologies should be used:
   - insecticide protected and unprotected trials
   - artificial infestation
   - paired plant analyses of infested and uninfested plants
3. The relationships between insect infestation and actual yield losses should be worked out.
4. A realistic and comprehensive estimation of insect related losses under farmers' situations should be conducted.

Discussion

Harris: Although considerable information is available on stem borer research, there is no central repository for these documents. CAB can assist in compiling existing information. However, informal publications from national programs will need to be added to the information base. This documentation effort can be taken up as a cooperative effort and CAB can be a contributor. We have an information base dating back to 1972. ICRISAT should serve as a focal point for collection and dissemination of information. We should start with *Busseola* and then move to *Chilo* and *Acigona.*

Kanwar: The CAB offer is welcome. The existing information can be made available in a few weeks. The missing information from national programs can be added to it. In case of species present in Africa, possibly agencies such as ODA may also be ready to help.

Lavinge: We should have an information base and then decide what is to be done. Areas of research should be identified and duplication should be avoided.

Kanwar: Recommendations quite often remain on paper, we should identify the people to undertake this documentation activity. I recommend that Dr Harris of CAB and Dr Saxena of ICIPE should prepare a critical review, with support from ICRISAT. A decision can be made later whether this material should be published or mimeographed for distribution.

de Wet: As we move the discussion forward I would like to have you consider the question, are borers important? What are incidence and damage levels?

Sithole: We have not worked on losses in Zimbabwe, but infestation may be as high as 70%. Actual losses are not known.

Lavinge: In Somalia, 100% of sorghum fields may show infestation, and 6-10% of the plants show dead hearts.

Nwanze: In West Africa, infestation may go up to 100%, but actual losses may only be 5%. Various estimates show 10-15% actual losses.

Seshu Reddy: In Eastern Africa we have conducted a number of surveys. About 10-75% losses are recorded due to all pests. Elaborate techniques are difficult to use on farmers* fields. Time of infestation determines the actual losses due to insects.

Wiseman: If you have a proper chemical control check, you can estimate the associated losses which may be attributable to all pests. Specific experiments may have to be set up for this purpose.

Saxena: Pheromones for monitoring *C. partellus* are not satisfactory and require further studies. However, *B. fusca* populations can be monitored effectively using pheromones. Some cultural practices also have the potential for reducing stem borer damage and may be mentioned in recommendations.

Harris: Cultural control has a potential, and varies according to local practices. There may even be need for proper legislation to take up such practices over large areas. However, we have not gone to that level yet.

Vidyabhushnam: Seasonal abundance and off-season carryover studies should be emphasized.

Amin: In IPM, what would you like to have as a major component?

Harris: Host-plant resistance.

Kanwar: People in national programs should indicate the type of training required, and the scientists and technicians should be identified who might benefit from participation in such training.

Nwanze: Apparently, equal weight is being suggested for different parameters for measuring insect damage. What is the justification?

Wiseman: Leaf damage should reflect plant resistance. Stem tunneling has been suggested for forage sorghums. Possibly, different types of resistance may operate at different stages.

Guthrie: It may turn out that we can infest at one stage only, if there is a good correlation in plant resistance across stages. However, resistance factors, e.g., DIMBOA concentration in maize changes with plant age.

Kanwar: A committee should suggest ways of evaluating materials for resistance. We should develop a network of people working for a common cause and agree on a common program.

Lavinge: A subcommittee should discuss what parameters should be measured for host-plant resistance in stem borer research.

Nwanze: We shall meet in the afternoon.

Seshu Reddy: We should also look into multiple pest resistance. Those interested in HPR should come together and collaborative arrangements should be made.

de Wet: We are planning to have a network of testing material for resistance to insects, diseases, and other traits.

Nwanze: We have started multiple pest resistance work, and the same is reflected in recommendations.

de Wet: I am now fully convinced that research on stem borers is an essential component of cereals improvement program.

Kanwar: One of the important contributions of

HPR is to stop the release of supersusceptible cultivars in the absence of cultivars with high levels of borer resistance. ICRISAT's Cereal Entomology Program should come up with proposals for discussion at the program level on future research on stem borers. It is time to revise our projects and make the necessary changes. Resistance to other insects should also be incorporated. The future technology should be modern, economical, and viable. Management of pests should be our aim, and needs to be cost effective. We should also think of millets. ICRISAT, ICIPE, and other institutions should work together and even justify and sponsor common workshops. Our approach should be interdisciplinary in nature. Entomologists and breeders should go hand in hand to make fast progress in HPR and pest management.

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