10th International Congress of Plant Protection 1983

VOLUME 3

Proceedings of a Conference
held at Brighton, England
20-25 November, 1983

Plant Protection for Human Welfare

ICPP

SA-S3

PROSPECTS FOR SUCCESSFUL INTEGRATED CONTROL OF BIOTIC YIELD-REDUCING AGENTS OF SORGHUM AND PEARL MILLET IN THE TROPICS

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ABSTRACT

Sorghum and pearl millet, staple cereals in the semi-arid tropics, are attacked by many pests of several kinds, from the seedling stage up to and after crop maturity. Some of the more important pests of these two crops are described, and possibilities for their control are discussed. Management practices, host-plant resistance, and pesticides are available, in various combinations, to control the pests of these crops, and more options will become available in the future. The combinations of pest control methods that farmers are able and willing to use, however, depend upon the interaction of several biological, social, economic, commercial, and political factors, and due attention must be given to all of these if effective pest control and sustained increased production of these crops is to become a reality.

INTRODUCTION

Sorghum (Sorghum bicolor) and pearl millet (Pennisetum americanum) are the staple cereals in the semi-arid tropics of South Asia and Africa where they are grown primarily as subsistence crops almost entirely on small farms. The grain yields are miserably low in these regions (400-600 kg/ha) compared with yields in more developed regions (2000-4000 kg/ha), where they are produced primarily for animal feed (FAO 1981). The low grain yields, combined with the high population growth rates in the African and Asian semi-arid tropics, have resulted in a steadily deteriorating food supply situation (World Bank 1979, IADS 1981). There is an urgent need to increase grain production from these two basic food crops in order to alleviate increasing problems of hunger and malnutrition and consequent human suffering, sub-optimal activity, and socio-political unrest.

We recognize that the low grain yields of these two crops on small farms in the tropics are the result of the actions and interactions of several biological, environmental, management, and socio-economic factors, and that there are no simple, easily-implementable solutions. As biologists our primary concern is with the interactions of biological, climatic, edaphic, and management factors and the development of production technology that in the appropriate social-political-economic climate will result in increased grain production on a sustained basis.

The most damaging pests of sorghum and pearl millet in the tropics include fungi, insects, bacteria, viruses, parasitic and non-parasitic weeds, and birds (Ferraris 1973, Tarr 1962, Teetes et al. 1980, Williams & Andrews 1983). There is a dearth of precise information on the yield losses caused by these pests, but we do know that they can be devastating, and can individually, on a local basis, cause yield losses in the 50-100% range. What the average overall losses are would be a guess, and our guess is in the 15-50% range, depending upon location and season (not included in these estimates are losses in opportunity to grow more-productive exotic cultivars because of their ultra-susceptibility to local pests).

The inability to be more precise on the overall magnitude of yield losses is due to insufficient information on the extent of damage by the various pests, and to the lack of information for several of them on the relationships between damage levels and yield loss. As integrated control requires the maintenance of pest levels below those that cause significant economic damage, it obviously requires that these latter relationships be known. Considerable resources are needed to conduct the surveys and yield-loss studies necessary to gain this knowledge.

In the limited space available we have chosen examples of different types of pests which are known to cause considerable damage during the seedling, pre-flowering, and post-flowering growth stages, and have used these to explore what might be done to develop integrated control programmes in these two crops in the tropics. We have not provided information on the problem of grain-eating birds, which is the subject of a specialist international programme recently summarised by Bruggers & Jaeger (1982).

SOME DEFINITIONS AND PRECONCEPTIONS

The term pest is used in a broad sense to encompass all living organisms that damage sorghum and pearl millet crops. The term integrated control, which we regard as including the more modish integrated pest management, is used to describe the employment of any or all suitable techniques and methods of pest control in as compatible a manner as possible to maintain pest levels in a crop below those that cause significant economic damage.

Sorghum and pearl millet are attacked by many different pests during crop development. In this situation integrated control does not necessarily imply the use of more than one control measure against one specific pest, but their use in the control of the complex of pests that damage these crops during their development.

The components available for integrated control programmes can be grouped into three general categories: (a) crop-management practices (often called cultural control); (b) host-plant resistance (which includes immunity, resistance, and tolerance); (c) externally applied chemicals (which can be protective and/or curative, and can be systemic or non-systemic). Farmers have traditionally used some of these control measures in an integrated way since the beginnings of agriculture. Such integrated control was developed empirically, and is generally adequate to prevent catastrophic crop losses (though losses are often considerable).

Transforming traditional systems to raise crop production potentials increases the potential magnitude of crop loss and the vulnerability to catastrophic pest attack. The development of new sets of integrated pest control practices is, therefore, an essential part of the development of a more productive and intensified farming system, to stabilize production at a much higher level.

CONTROL OF SEED AND SEEDLING PESTS

The planted seeds and subsequent seedlings are highly vulnerable to pest attack. The seeds can be removed or damaged by insects prior to germination, e.g. termites (Hodotermes spp.) and ants (Messor spp.) can cause considerable loss of planted seed, causing losses in plant stand that cannot be adequately compensated for later. When the seedlings are emerging and for several days after emergence they are vulnerable to attack by soil-inhabiting insects, e.g. cut-worms (Agrotis spp.), by unspecialized plant pathogens such as Pythium spp. and Fusarium spp., by specialized pathogenic fungi such as downy mildews (Sclerospora graminicola, Peronosclerospora spp.), by shootflies (Atherigona spp.) and the parasitic witchweeds (Striga spp.). These may kill the seedlings, causing reduced plant populations, or cause reduced growth and productivity in surviving plants. Factors that delay seedling emergence and/or reduce seedling vigour, such as soil crusting, waterlogging or drought, increase the vulnerability of seedlings to these pests.

Increased seeding rates have traditionally been used to partially compensate for anticipated stand reduction, but this is wasteful of valuable seed, and is not effective for the problems that become evident some time after the seedling stage such as downy mildew and witchweed. More-direct methods are available to control several of the seedling pests and they are discussed below.

Unspecialized seedling pests

It is unlikely that host-plant resistance will be found effective for the control of unspecialized seed and seedling pests. As indicated above, certain management practices can be used to compensate for or help reduce the effects of the unspecialized seedling pests (over-seeding, prevention of crusting, waterlogging, drought), but the most effective direct control measure for this group of pests is treatment of seed with systemic pesticidal chemicals.

The advantages of seed treatment for the control of unspecialized seedling pests are: (a) small quantities of pesticides are needed at seeding rates of 5-10 kg/ha and application rates of 4-8 g product per kg seed, which is economical and causes minimal environmental hazard; (b) no expensive or complicated application equipment is required for treatment, nor a high level of farmer technical skill; (c) no extra labor or extra water has to be obtained for treatment, thus keeping application costs low.

If local researchers can clearly establish what are the important local seed and seedling pests of sorghum and pearl millet, suitable pesticide mixes can probably be developed for use as a seed treatment for effective control of these pests.

Specialized seedling pests

Shootflies

Shootflies lay eggs on young seedlings of sorghum and pearl millet (though they are a more serious problem on sorghum), and the larvae kill the growing points while feeding, causing the characteristic dead-heart symptoms. The intensity of infestation can be effectively controlled by management, pesticides, and by host plant resistance.

If all the sorghum crop in an area is planted at the same time, with the first rains, then damaging infestation is normally avoided, for by the time the fly population has built-up to what would have been damaging levels, the plants have passed the stage of high susceptibility. Later planted fields, or fields in which seedling growth is retarded, thus extending the period of susceptibility, are the most vulnerable to severe attack and need to be protected by one or more of the other available control measures.

Granular formulations of systemic insecticides such as carbofuran, applied in the furrows or seed pockets along with the seed, can effectively control shootfly in sorghum (and presumably also in pearl millet) (Vedamoorthy et al. 1965, Barry 1972). Research in India over several years has clearly identified sorghum genotypes that in a multiple-choice high-challenge field-screening situation are consistently much less damaged by shootfly than most other genotypes (Jotwani & Davies 1980). More research is needed to determine the mode(s) of action of this apparent resistance, and to actively incorporate it into high-yield cultivars.

For the immediate future, available control measures are timely planting and systemic insecticides applied along with seeds. It is possible, however, that within 5-10 years agronomically desirable cultivars will be available with moderate to high levels of shootfly resistance. The purchase of high-cost systemic insecticides will not be an economically viable option for most small-scale farmers; therefore the early planting option will be the major method of shootfly control in the foreseeable future.

Downy mildews

The fungi that incite the downy mildew diseases of sorghum and pearl millet survive in the soil, and with the seed, as thick-walled resting spores that are somehow triggered to germinate and infect young seedlings. They then colonize the growing points of the infected plants, causing systemic disease in the organs differentiated after growing-point colonization, including the inflorescence which is rendered partially or completely sterile depending on the stage of development at which growing-point invasion occurs. Little or no compensation in yield by non-diseased plants occurs, because diseased plants often compete for environmental resources right up to maturity but produce no grain.

The two major methods available for control of downy mildews are host-plant resistance and seed treatment with the systemic fungicide metalaxyl (Williams & Singh 1981, Anahosur 1982). Sources of resistance to Peronosclerospora sorghi in sorghum and Sclerospora graminicola in pearl millet are available and are being actively utilized (Williams 1983).

Seed treatment with metalaxyl could have immediate impact on production of pearl millet in West Africa where average annual yield losses from downy mildew are estimated to be about 10%, and individual farmers losses can be as high as 50% (King & Webster 1970, Williams 1983). The use of metalaxyl seed-treatment on cultivars highly susceptible to downy mildew should, however, be avoided, for that would provide a high selection pressure on the pathogen for the selection of pathotypes with reduced sensitivity or even resistance to the active ingredient of this fungicide. The combined use of host-plant resistance and seed-treatment with metalaxyl would probably provide effective long-lasting control.

Witchweed

The witchweed survives the long dry-season of the semi-arid tropics in the soil as a seed which is triggered to germinate by exudates from the host-seedlings roots. The root of the germinating witchweed plant rapidly penetrates the host root and absorbs from the host-plant nutrients for the developing witchweed plant. In severe infestation many witchweed plants may parasitise one host-plant, causing stunted growth and low or no grain yield. Each season the witchweed plants flower and subsequently scatter large numbers of tiny seeds to infest future crops.

This pest is one of the most difficult to control for there does not appear to be any effective and feasible short-term management control practice. Control with conventional herbicides is also difficult, because much of the damage is done to the host-plant before the parasite emerges from the soil. What is needed is an herbicide effective against the witchweed but with no effect on the hosts, that could be applied as a seed-dressing or in-furrow treatment, and that would be translocated into the developing root systems of the young host-plants and kill the invading witchweed roots (a very unlikely discovery?).

The greatest possibility for effective control of witchweed in the future appears to be with host-plant resistance. Research in India with *Striga asiatica* and in Africa with *S. hermonthica* indicate the availability in the sorghum germplasm collection of genotypes that can resist severe infestation by this pest (Ramiah & Parker 1982). The realization of this potential depends upon the plant breeders, but 5-10 years from now *Striga*-resistant sorghum cultivars could be available, and there does not appear to be any reason why the same could not be done in pearl millet.

CONTROL OF PESTS OF ADULT PLANTS

Pests of vegetative plant organs

Stem borers

As sorghum and pearl millet plant stems begin to thicken they become targets for several species of stem-boring *Lepidoptera*, which on younger plants can cause "dead-hearts", but are recognized primarily by the stem-tunneling habits of the larvae as they feed in adult plants. Extensive tunneling of stems and peduncles can occur, with or without collapse or breakage of the tunneled organ. In pearl millet, stem-borer infestation appears to be greatest in the West African Sahel region, whereas sorghum is attacked by stem-borers on a much wider scale. Regional variations occur in the predominant causal species, e.g. Chilo partellus and Sesamia inferens are the main stem-borers of sorghum and pearl millet, respectively, in India; Busseola fusca and Acigona ignefusalis, respectively, in West Africa.

Stem borers are difficult to control. Oviposition sites and larval behaviour make them difficult to reach with conventional insecticide sprays. The use of granular systemic insecticides, however, can provide satisfactory control, but their use by small-scale sorghum and pearl millet farmers in much of the tropics is not likely to be widely adopted for some time, for several reasons.

There do not appear to be any management practices that can be utilized in more productive farming to control the stem borers, though it would probably be worthwhile to make further studies on the traditional farming systems and the bionomics of the particular stem borers in the region where control is to be practiced. The overwintering of the pest appears to be a promising area for further evaluation of possible management control. In India, C. partellus survives the long dry-seasons in dried sorghum stalks which are used primarily as animal fodder. Just how to eliminate the pest but maintain the fodder in an edible and easily stored form will be the main puzzle to solve.

Research is underway in several sorghum improvement programmes to find and use host-plant resistance to stem-borers. Effective screening techniques have been developed and major differences detected in susceptibility among genotypes in no-choice systems (Seshu Reddy & Davies 1978). So, it is feasible that 5-10 years from now high-yielding cultivars of sorghum will be available with a high level of host-plant resistance to stem borers. Work with pearl millet is some years behind.

For the immediate future, farmers will have to avoid planting highly-susceptible cultivars, or have access (physical and economic) to, and be able to apply safely, granular systemic insecticides.

Fungal leaf pathogens

Sorghum and pearl millet leaves can be infected by many fungal species causing spots, lesions, and pustules of various colours, shapes, and sizes (Williams et al. 1978). The result is a reduction of photosynthetic area with possible significant reduction in source of carbohydrate to fill the grain. Information is generally lacking on the relationships between the degree of leaf-blade destruction, the stage of crop development, and the consequent yield loss. It is probable that a high level of destruction of the lower leaves of the plant during the later stages of grain filling has little or no direct detrimental effect on grain yield (though fodder value could be significantly reduced), and that a high level of leaf disease before flowering would have a significant negative effect on yield.

Although systemic fungicides are available that could control the various fungal leaf pathogens of sorghum and pearl millet, there is little chance that they will be used by small-scale tropical farmers on these two crops, for several technical and economical reasons. In the absence of reliable management practices to control leaf diseases, the responsibility for keeping the leaf diseases of sorghum and pearl millet under control must lie with the plant breeders. In the development of new cultivars, routine tests for susceptibility to the potentially-important local leaf pathogens should be conducted, and corrective measures taken when susceptibility is detected.

Pests of inflorescences

Specific inflorescence pests

The major specific insect pest of sorghum inflorescences is the midge (*Contarinia sorghicola*). The tiny fly oviposits under the glumes of young florets, and the entire development of the larvae and the pupae is within the protective covering of the glumes resulting in complete floret sterility. The synchronisation of flowering time within a region (how big an area it should be remains to be determined), along with avoiding the use of highly susceptible cultivars, appears to be the only practical control measure at present for this important pest. It is technically very difficult to apply insecticides to the well-protected eggs and larvae, even on experimental stations, and these technical difficulties along with economic considerations make untenable the use of insecticides for the on-farm control of midge.

The smuts (*Sphacelotheca* spp. and *Tolyposporium* spp.) are the most important and widespread specific fungal pathogens of sorghum and pearl millet inflorescences. These fungi infect florets before fertilisation and develop in place of the grain, producing masses of fungal spores. The smuts can be divided into those that infect the inflorescences systemically, having infected the seed embryo the previous crop season or having infected the young seedling from seed- or soil-borne inoculum (*Sphacelotheca* spp.), and those that infect directly from air-borne inoculum reaching the florets after inflorescence emergence from the boot (*Tolyposporium* spp.). These two modes of infection have major implications for control opportunities. The seed- and seedling-infecting smuts can be readily controlled by seed-dressings with systemic fungicides prior to planting (Tarr 1962). The floret-infecting smuts, however, are extremely difficult to control with fungicides, for the requirements of the timing and placement of the fungicide are too precise for practical large-scale field use. Thus for the second group of inflorescence-infecting fungi, host-plant resistance and/or management practices will need to be used to obtain successful control.

Less-specific inflorescence pests

Efforts of sorghum breeders in the last 15 years have resulted in the development of cultivars with high potential grain yields, which in the most part are characterised by more-compact inflorescences and earlier flowering and maturity than traditional cultivars. This earliness, necessary to ensure better soil moisture for improved grain filling, and the more compact head habit, has led to increased damage from unspecialized grain-feeding bugs (head bugs) and unspecialized grain-mold fungi (Williams & Rao 1981). Though pesticides are available that are highly effective against these pests, the technical and economic difficulties of getting sufficient quantity of the chemicals to the developing seeds are enormous and preclude pesticidal control. If such compact-headed and also early sorghums are needed in order to increase yield potential, then resistance to these unspecialized inflorescence pests will also be needed in order that the yield potentials can be realised.

PROSPECTS FOR INTEGRATED CONTROL

As indicated earlier, sorghum and pearl millet farmers have used integrated control systems to control pests of these two crops for a long time. So, what we are really discussing are the prospects for the development of more-effective, higher levels of integrated control to (a) further reduce pest damage levels in traditional cropping systems, and (b) reduce pest problems to insignificant levels in more intensified cropping systems with new high-yield cultivars. Both are important if the ever increasing food gaps are to be plugged.

We have indicated above the currently available options for controlling some of the more important pests of these two crops. It is clear that (a) host-plant resistance can be found effective against most pests (exceptions include the unspecialized seedling pests),(b) systemic chemicals that prevent or even eliminate established infestations of most pests exist or can be developed (present exceptions include witchweed and midge), and (c) management practices can be employed that reduce pest challenge levels (but are sometimes incompatible with the requirements of intensification of crop production). The combinations of pest control methods that farmers eventually adopt will depend upon the interaction of several factors including: (a) the perception of the potential damage and crop loss, (b) the yield-level expectation, (c) the knowledge of possible control measures, (d) the physical availability of the components of the possible control measures, (e) the economic availability of the components, (f) the technical ability to use the control measures effectively and safely, and (g) the level of likely economic return for the extra investment, effort, and risk.

The countries in which sorghum and pearl millet are grown as staples vary markedly, on a continuum from those that have well-developed agricultural research programmes, seed industries, extension services and representation of commercial companies to those that have virtually no effective research and extension services, no seed industry, and are not on the commercial companies' maps. The possibilities for adoption of integrated pest control systems at farm level will depend just where along that continuum a particular country occurs, and the degree of actual adoption will depend on the interactions listed above.

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