CHAPTER 1

THE *STRIGA* SCOURGE IN AFRICA: A GROWING PANDEMIC

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Witchweeds (*Striga* spp.), endemic parasitic weeds of sub-Saharan Africa are steadily increasing their geographic domain and level of infestation, and bewitching plants they invade, thereby greatly reducing crop yield. They have become a widely acknowledged scourge. The *Striga* problem undermines the struggle to attain food security and economic growth in the continent. Countries with nascent infestation of *Striga* only 25 years ago are now showing heavy annual losses of crop yield. Rough estimates are nearly 300 million people in sub-Saharan Africa are adversely affected by Striga, and up to 50 million hectares of crop lands in the continent show varying degrees of Striga infestation. Areas of otherwise productive agriculture have been abandoned because of this scourge. Crops previously unaffected by *Striga* are now showing serious infestation. *Striga* is, therefore, fast becoming a pandemic of serious proportions in Africa because of its vast geographic spread and its economic impact on millions.

1. Introduction

1.1. *The Problem*

Striga has long been recognized as the greatest biological constraint to food production in Africa as nearly 100 million hectares of the African savannah are infested annually with *Striga*. Although these parasites attack several crops, the brunt of the ravage has fallen on the staple crops of the poor in the African savanna, namely maize, sorghum, pearl millet

(*Pennisetum glaucum*), upland rice, and cowpeas (*Vigna unguiculata*). *Striga* damage to crops is often severe because of its remarkable bewitching effect on crops it invades. The *Striga* problem in Africa is exasperated by its exquisite adaptation to the climatic conditions of the semi-arid tropics, its high fecundity, and longevity of its seed reserves in tropical soils. The growing conditions in sub-Saharan Africa permit timely breakdown of seed dormancy and conditioning of *Striga* seeds and exposure to exudates from host seeds planted around them. Its many flower stalks each produce and deposit a new supply of tens of thousands of tiny seeds to an already enormous seed bank (Chapter 2). The large number of parasitic seeds produced increases the chance that some *Striga* seeds will find a suitable host. Every year some seeds germinate, some revert to dormancy, some remain in the soil unconditioned, while others are added from the new growth, continually enriching the seed reserve in the soil. The type of crop cultivars grown has a direct influence on *Striga* infestation. The best practice is long term rotational cultivation of cereal crops with legumes or other crops unaffected by the parasite. Continuous use of susceptible crop cultivars without protective amendments leads to disastrous levels of heavy infestation, crop failures, and build up of the *Striga* seed reserve in the soil.

Local landraces are often described as having tolerance to *Striga*. However, the moderate level of tolerance exhibited by local landraces in the past may no longer provide protection at higher levels of infestation. Local landraces behave similarly to susceptible cultivars at high infestation levels, supporting more *Striga* and bringing more parasitic plants to set seed, further enriching the soil seed bank. Where the *Striga* infestation is high, only cultivars with high levels of *Striga* resistance would provide protection and help diminish the seed bank.

1.2. *The* Striga *Scourge*

The production of crops under African soils and climatic conditions is wrought by a number of agronomic and management challenges. *Striga* is only one of several biotic, climatic, and edaphic problems reducing crop yield, directly marginalizing capacity for food production in the continent. However, severe *Striga* infestation appears to render African farmers helpless and often bewildered, even though they are otherwise very resilient and adaptive. Because of the seemingly sudden build up of *Striga*, its dramatic bewitching effects on crop plants, and widespread dreadful affliction and devastation, African farmers recognize *Striga* less as a biological constraint to crop production and more as a scourge handed from above.

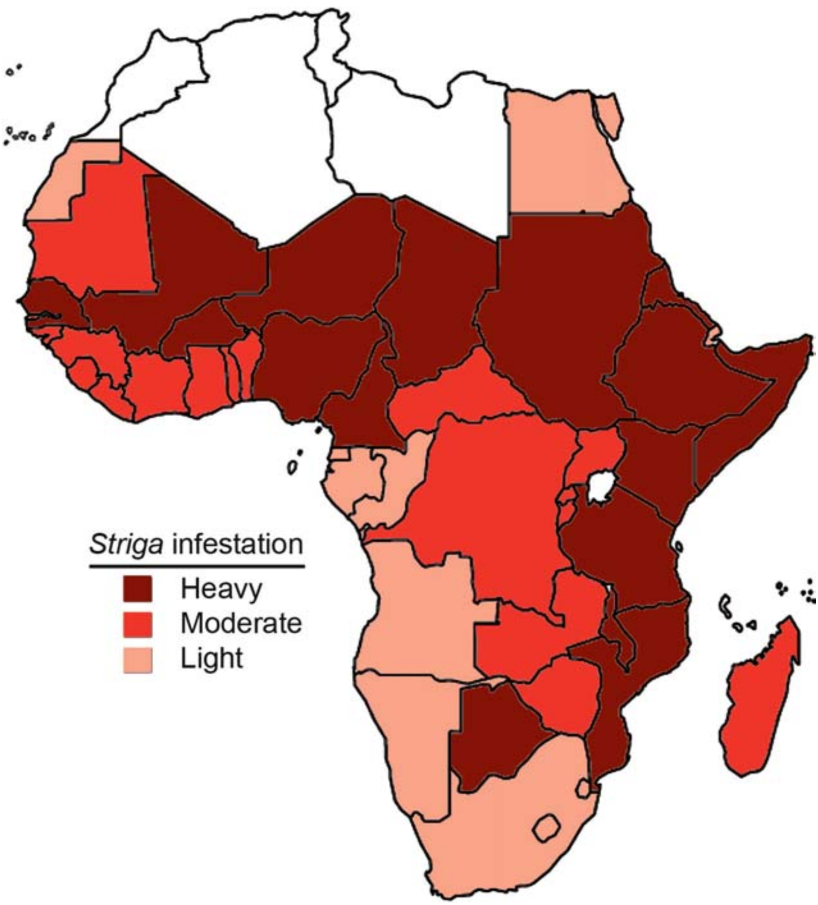

Figure 1. Striga *infestation in Africa is most severe in the most food insecure areas. One or more species of the parasite are found in crop lands and/or grasslands of nearly all African countries below the Sahara. Adapted from a report by Gressel and colleagues.*[8]

Across the continent, farmers ascribe local names to *Striga* that so aptly translate to effects on humans of evil spirits or serious illnesses. While the parasite is still invisible underground, it causes the crop to suddenly turn sickly, apparently bewitched. Its annual occurrence and wide geographic spread affecting large proportions of farmlands and populations also give *Striga* the appearance and feel of a natural pandemic. What is most baffling to African farmers is that *Striga* is not a new problem, as it has long been a common occurrence in crop fields. Yet, the sudden expansion of its spread and the rampant high infestation levels are harder for farmers to comprehend. Farmers continue to manage the problem with knowledge and practices passed on to them from earlier generations. Unfortunately, practices such as hand weeding that may have contained the *Striga* problem at low levels of infestation in the past are not making a dent in the serious rampant infestation so common around them today. Surveys conducted in some of these *Striga* endemic areas (e.g. Chapter 20) reveal the seriousness of this scourge. More than half of African farmers recognize that *Striga* infestation is on the increase on their farms as well as on their neighbors', that they have not had it so bad before, and do not know how it is spread or how best it is managed. Almost all farmers interviewed identify *Striga* as the biggest challenge in their efforts to produce food for their families and in the community around them.

1.3. *The Striga-Poverty Parallel*

Striga is a poor farmer's problem, a direct result of demographic and economic pressures in a farming community. There is a near perfect ecological overlap between areas of *Striga* infestation and where the poor farm and reside, and where hunger prevails (Fig. 1). These regions are often characterized by low rainfall and degraded, infertile soils. The impact of *Striga* is, therefore, compounded by its predilection for attacking crops already under moisture and nutrient stress, conditions that are very common in much of the semi-arid tropics. There is growing evidence that the *Striga* problem is worsening across sub-Saharan Africa.[1] The world's population is projected to grow to 8 billion in 2025, stabilizing at about 8 billion people by the middle of the 21st century.[2] During the same period Africa's population is projected to rise to 1.5 billion in 2025 and 2 billion by 2050, although the projected population growth may vary from region to region. These are ominous trends for African agriculture unless corrected by the introduction of modern technologies to accelerate a concomitant growth in food production. Poor African farmers have limited access to formal education or vital information. They are generally recalcitrant to adopting new technologies, and are risk averse. As a result, rapid population growth in rural Africa has created pressure on availability of farm lands, forcing crop agriculture onto marginal lands with poor soil fertility, poorly drained soils, and soils with acute moisture stress. The *Striga* problem has been worsened and crop yields reduced by farming practices with shortened or no fallow periods, little or no use of inorganic fertilizers because of cost, and low values paid for the crop, increased use of mono-cropping, and continuous cultivation without traditional practices of crop rotation and intercropping systems. Farmers with crop fields severely infested with *Striga* often resort to abandoning their fields, contributing to an already severe pressure on availability of farm lands. *Striga* has expanded to cover a wider ecological range encroaching into previously un-infested crop lands and invading new crops.[3] These realities have worsened the *Striga* problem raising it into a growing pandemic and an agricultural scourge of significant proportions to subsistence farmers in very many African countries (Fig. 1).

2. Distribution and Impact of Striga

2.1. *Geographic and Species Distribution*

The genus *Striga* includes over 40 species, of which 11 species are considered parasitic on agricultural crops (Chapter 6). Africa is thought to be the center of origin for *Striga*. The prevalence and extent of genetic diversity of a species in a particular geographic area, where more forms appear and specialized associations are observed, are often indicators of origin for plant species. The vast tropical savannah between the Semien mountains of Ethiopia and the Nubian hills of Sudan has the greatest biodiversity of sorghum and pearl millet, the two crops that *Striga* readily infests, as well as that of the parasite population itself. This area is recognized as the center of origin for sorghum and pearl millet[4] and may also be the home of the two species of *Striga* affecting cereals, namely *S. hermonthica*, and *S. asiatica*. The species that is specially adapted as a pest of legume crops, *S. gesnerioides*, may have originated in western Africa. Today, *Striga* is found in almost all regions of sub-Saharan Africa, except in areas where rainfall is too high or in high altitude areas where temperatures may be too low for development of the parasite,[5] but is most severe in infertile, nutrient depleted soils with low organic matter content.

S. hermonthica has the largest geographical distribution. With its obligate out-crossing behavior and its large plant stature, it is the species that causes the greatest crop damage. *S. hermonthica* is found in much of sub-Saharan African with particular prevalence in western, central, and eastern Africa, as well as parts of the south-western part of the Arabian Peninsula across the Red Sea.

S. asiatica has its widest distribution in the eastern and southern Africa. It is also found in Asia, particularly in southern India, as well as the United States and Australia. *S. gesnerioides* occurs in Africa, the Arabian Peninsula, the Indian subcontinent, and has also been introduced to the United States.[6] This species causes its greatest economic damage on legume crops widely grown in western Africa, particularly cowpeas. Both *S. gesnerioides* and *S. asiatica* are self-fertile resulting in apparent genetic variability observed as distinct morphotypes as well as parasitic specialization. They appear to be distinctly less variable than the obligately out-crossing *S. hermonthica.*

2.2. *Dispersal and Expansion of Infestation*

There have been limited studies on the modes of spread and dispersal of *Striga* seeds. Farm practices as well as human and animal movements across geographic areas have been implicated as factors responsible for spreading parasitic weed seeds. Crop seeds are a major vehicle for *Striga* seed dispersal, with 20-40% of seed lots in the market contaminated by

Striga seeds.[7] Most African farmers grow their own "seed", saving grain from a previous crop. Yet, there is always a significant activity of seed exchange among farmers within and among distant neighborhoods. Grain consignments distributed as "food aid" and "seed aid" often result in widespread serious *Striga* infestations.[8] Even when improved crop cultivars are deployed, there are no functional seed production and dissemination programs in most African countries. Where public seed agencies are in place, they are often non-functional, producing under-par quality seeds, or are not producing enough to meet needs. The private seed industry is in its infancy in Africa, but well-functioning seed enterprises that supply certified, brand quality seed to farmers are badly needed. While true-to-type, quality-controlled seed is essential for increasing productivity, it will have the additional benefit of limiting the spread of parasitic weed seeds. Better farm sanitation, handling of farm equipment, and management and movement of crop residues on farm also are important in curtailing dispersal and spread of parasitic weed seeds. Educational programs are vital that promote the value of quality seed, proper sanitation, and handling of equipment and crops as a way to effectively address this important problem in *Striga* endemic regions.

There seems to be physiological specialization in *Striga*, as some strains cross-infect host plant species and others do not. In some places *Striga hermonthica* "strains" that infect sorghum are different from those that infect millet or maize. Where there has been distinct geographic or ecological separation of regional crop cultivation in Nigeria, Niger, Burkina Faso, and most of West Africa, it appears that different specialization of host strains has developed. In such situations, a crop introduced to the new region will initially be unaffected by strains of *Striga* that are there, but will gradually succumb to infestation. Is this specialized physiological adaptation or the result of introduction into the new area of strains with a capacity to attack the new crop? In the early 1980s pearl millet was introduced to the eastern Sudan from the western part of the country where it is mostly grown. It was unaffected by the strains of *Striga* in the region. Several years later, pearl millet was equally attacked by *Striga* east or west of Khartoum. In other areas, there are no separate geographic bands for strains specific to a crop species. Very often when sorghum and millets are grown in the same region, both crops show similar degrees of *Striga* infestation, although it is not always easy to determine if these strains are different, related, or the same. Occasionally, an unusual pattern of *Striga* infestation is observed, such as the situation in western Eritrea. Although the area is long known as a hot spot for *Striga* infestation, and sorghum and pearl millet are major crops of the country. Sorghum is always highly infested, yet pearl millet in Eritrea has been cultivated totally free of *Striga*. Crops that were never known to be affected, such as barley, wheat, and tef have been seriously infested.[20] The bases for some of these observations and events are not well known, and merit serious investigation. We also have information accumulating on the inheritance of host plant resistance in several crops, but little is known of the genetics of virulence of parasite populations. The diversity and structure of parasitic populations in the economically important *Striga* species is hardly understood.

2.3. *Economic Importance and Impact*

That parasitic weeds are significant constraints of crop production in much of Africa is widely recognized. However, hard data on the extent of spread, yield losses, impact on the economy and welfare of nations or households have not been available, except for the few reports[3,7,9-12] that continue to be repeatedly cited. These estimates, rough as they are, have examined national and regional impact of parasitic weeds and have been useful, but they pose some limitations in extrapolating to continental impact. In general, average yield losses due to *Striga* are estimated at or above 50%. The total area under severe to moderate *Striga* infestation had been estimated to range from 30 to 50 million hectares.[3] Nevertheless, estimates on the extent of crop damage in a country or region in the African continent vary depending on prevalent cultural practices, the crop cultivar, and degree of infestation.[13] Much spread has occurred since these early and rough estimates were made, but no new figures have emerged. The degree of *Striga* infestation is most severe in eastern Africa where invasion by the parasite is expanding at an alarming rate, often resulting in total loss of crops in any given crop season. Expansion of *Striga* infestation has also increased in western Africa.

The annual crop production in the savanna regions of Africa alone was estimated to have a significant negative impact on the food supply of over 100 million people two decades ago[14], and the situation is getting worse.[3] The Food and Agricultural Organization (FAO) of the United Nations estimates that, across the continent, *Striga* causes annual losses in excess of US$7 billion, adversely affecting over 300 million people.[1]

3. *Striga* Management Options

It is generally believed that with abundant resource commitment, parasitic weeds can be managed in agriculture. However, the sufficiency of currently available technologies for effective *Striga* management is debatable. Strategies may be directed to the alternative management options of *Striga* control, containment, or eradication. Control of *Striga* is slow but feasible. *Striga* damage and infestation can be somewhat alleviated with well-managed practices and measures that fit the local knowledge, economy, as well as labor capacities, and practiced for several seasons. Four independent *Striga* control approaches, namely cultural, chemical, genetic, and biological options have been widely investigated and developed, and are described in other chapters. In most cases, these control measures have had limited success. Effective control of *Striga* has been difficult to achieve through conventional hand or mechanical weeding as the parasite exerts its greatest damage bewitching the crop before its emergence above ground, and providing evidence for host plant infection. Suggested cultural practices involving crop rotation, trap cropping, intercropping, or multi-year fallow, are not adopted.[15] These practices are perceived by poor farmers as unaffordable or uneconomical, labor intensive, impractical, or not congruent with their other farm operations. An intriguing new concept dubbed "push-pull", which employs co-planting of different crop species between rows in a maize field (repellent, push), and another crop around the field (attractant, pull) to control two major biotic problems of maize (stem, insects and *Striga*) is discussed in Chapter 18. Its wide adoption will hinge on finding suitable companion and trap crops that fit into the farming systems of target communities. Many of these management options are effective practices that not only offer *Striga* control, but also build up soil fertility, organic matter, as well as enhance overall soil health. These practices also require several years of repeated and continued application before their effects are realized through a significant rise in annual grain yield, or as an apparent reduction in level of infestation. The use of resistant crop cultivars is the most economically feasible and environmentally friendly means of *Striga* control. *Striga* resistant cultivars have been bred in a number of crops, as discussed in later chapters. However, cultivars with immunity to *Striga* have not been found in any host crops. Multiple genes for *Striga* resistance, found so far only in sorghum, have been pyramided in cultivars that also possess desirable genes for agronomic and grain quality traits (Chapter 7).

Biocontrol of *Striga* has also recently emerged as a potential control measure (Chapter 21). Natural enemies of *Striga* have been found in insects, fungi, and bacteria. However, current biocontrol agents are probably not effective enough to be deployed *per se*, but are applicable as part of an integrated approach. Seed coating of non-transgenic maize with a low dose of herbicide was recently developed and released in Kenya, but will need a slow release mechanism to last the whole season in long season maize (Chapter 11).

In general, only a few of these control measures have been widely adopted or commercialized. *Striga* continues to inflict significant yield losses on staple crops of Africa impacting the state of food security in Africa. The reasons for limited adoption of these control practices include limited knowledge of the problem, its biology, the lack of labor or resources to make the needed investment, an uncertainty of potential control, and a return to investment, and an unwillingness to make the long-term investments.[16]

A new infestation of *Striga* can also be contained into a small geographic area, again with sufficient resource commitment. The most successful experiment of containment took place in the United States, where a seemingly nascent level of *S. asiatica* infestation was discovered in the state of South Carolina.[17] *Striga* infestation was beginning to spread when a highly organized campaign started including effective quarantine of seed movement, sanitation, and application of costly chemical applications to destroy emerged parasitic weeds above ground as well as seeds in the soil. Nevertheless, it took more than 40 years and over US$250 million to contain *Striga* infestation into two counties of the Carolinas.[18]

Eradication of *Striga* or other invasive species is difficult to achieve especially after a major infestation. Examples of successful eradication of invasive species are hard to find.[19] Eradication is unattainable because several small unnoticed centers of nascent infestation may spread into larger areas. Attacking nascent foci becomes valuable if long-term eradication is to be attained. This is particularly true in species such as *S. hermonthica* with its large plant size and immense seed production capacity.

4. Investments in *Striga* Control

Significant advances have been made in understanding the biology of parasitic weeds and in devising technologies that can be used for their control. However, this progress has been slow and inadequate to significantly impact lives of rural farmers. A major reason for this insufficient progress is the lack of significant investment into the research and control of *Striga*. Past investments have not been commensurate to the magnitude of the problem. The *Striga* problem has become too big for any resource commitment by national programs of many developing nations. There is also an insufficient scientific base to address the problem in a meaningful way in many of these countries. National or regional efforts directed to *Striga* management will need to place a mix of scientific expertise with resource support. Intractable biological problems such as *Striga* infestation require new knowledge. Such resources may not exist in the emerging scientific and development organizations of most developing countries, and may require external input or regional cooperation.

There have been several, albeit intermittent, international investments into *Striga* research. The International Development Research Center (IDRC) of Canada provided much of the early support in *Striga* research in the 1970s and 1980s, particularly with their uncommon model of providing national talent in developing countries with direct resource support and encouragement. Early advances in breeding of *Striga* resistance in sorghum were catalyzed by this IDRC investment. The British Overseas Development Agency (ODA) as well as the German technical support program (GTZ) have also provided significant support to *Striga* research. Much of this research was devoted to testing and retesting promising cultural practices. Agronomic research tends to be location specific. Basic research was badly needed to understand how *Striga* parasitizes and where its weaknesses lie.

The most sustained and significant resource support for *Striga* research has been provided by the United States Agency for International Development (USAID) and the Rockefeller Foundation. These two agencies should be credited for the development and deployment of the only two commercially launched technologies for *Striga* control, namely *Striga*-resistant sorghum cultivars deployed as an integrated *Striga* management technology in Ethiopia, and the seed-coating of imazapyr-resistant maize in Kenya.

5. The Current State of Knowledge

Although successes in on-farm *Striga* control have been limited, the global research community has laid a good foundation of knowledge about the nature of the parasite pointing to potential avenues for intervention. There has been an enhanced understanding of the biology of the parasite and its interaction with crop plants and other hosts. This knowledge-base continues to be built as can be gathered from the chapters in this book. Knowledge is also emerging on the basis of specificity of *Striga* adaptation to different hosts and to different environmental conditions. New molecular biological tools with potentially promising applications for *Striga* control, coupled with the emergence of genomic sequences of major agronomic crops. These serve as hopeful signs that effective management and control of *Striga* may be nearer than the horizon.

There is also much that is not yet known about the parasite. The behavior of the parasite under natural conditions is not well understood. We do not fully understand why *Striga* behaves erratically in nature. The interaction with the environment in which *Striga* so readily thrives and the extent to which these variables determine annual crop infestation are also not well understood. The germination of *Striga* in the field or even in laboratory conditions is not predictable, nor do we always know what parameters to alter to obtain predictable results. We have insufficient and often conflicting information on how the soil pH, soil microbial activity, soil organic matter, and the degree of soil mineralization impact *Striga* infestation.

6. The Challenge

There is no doubt that, if left unchecked, the *Striga* problem in Africa will continue to lead to disaster. *Striga* will ruin farm communities and destroy fragile ecosystems that are managed by poor subsistence farmers, turning an already precarious state of food production into an even greater continental crisis.

There is sufficient knowledge to develop interim technologies for the control of *Striga*, but more needs to be learned for even greater impact. This book is written with the premise that none of the currently available technologies can provide sustainable solution to the *Striga* problem. Conquering this scourge requires a good mix of disciplinary approaches towards the development of an integrative approach that will bring together multiple control factors. The theme and purpose of the conference that led to this book was to promote integrated *Striga* control as a sure way to synergize scientific approaches and generate greater impact. Successful experiences were shared and the challenge for the next generation of integrated technologies was extended. Hopefully, this challenge will be met and the growing scientific talent pool and the prowess of the emerging scientific capabilities and tools will be able to conquer this scourge and avert disaster.

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