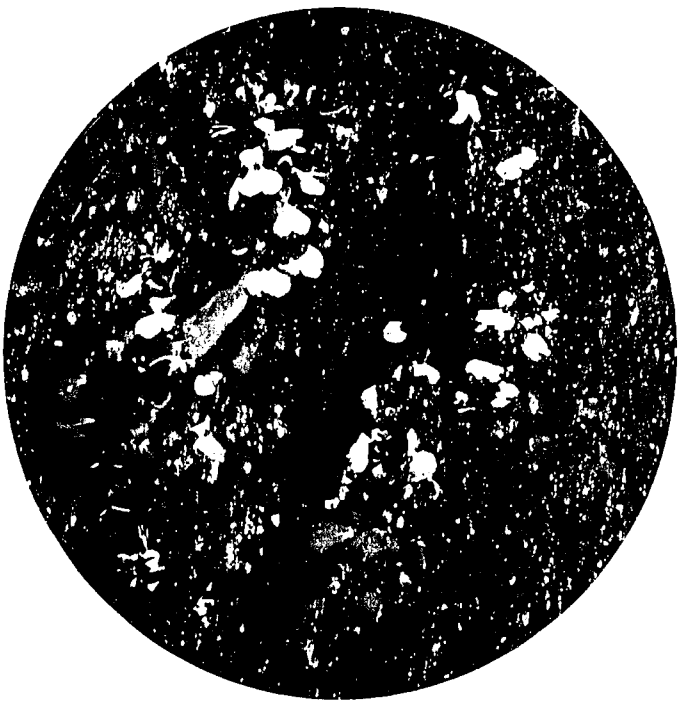
STRIGA: Scourge of African Cereals



INTSORMIL

Fighting Hunger with Research...A Team Effort

INTSORMIL

International Sorghum and Millet
Collaborative Research Support Program

University of Nebraska
241 Keim Hall
Lincoln, NE 68583-0723
Telex 43807 UN INTPRG LCN Telephone (402) 472-6032

Funding Support through Agency
for International Development
Grant: DAN-1254-G-SS-5065-00

INTSORMIL Publication Number 89-1
1989

INTSORMIL Institutions are
affirmative action/equal opportunity institutions.

Striga: Scourge of African Cereals

Larry G. Butler[1]

Striga, a beautiful but enormously destructive weed, interferes with production of the native African cereals sorghum and millet as well as maize and cowpeas. These crops provide the staple foods for millions of people in the semiarid regions south of the Sahara.

Recent trends away from traditional fallowing practices toward continuous cultivation of cereals to meet increasing population pressure have intensified the *Striga* problem. Some authorities now cite *Striga* as the greatest biological constraint on cereal production in Africa.

A sorghum field severely infested with *Striga*. (Photo courtesy Dr. Dale Hess)

[1]Professor, Department of Biochemistry, Purdue University.

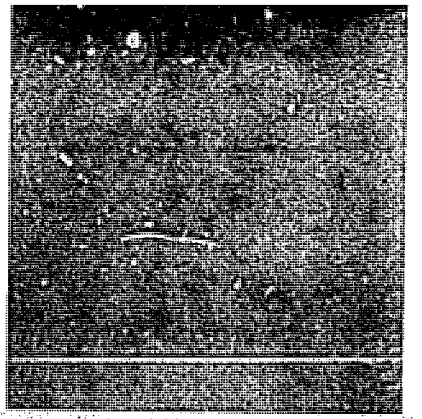
Drs. Babiker and Butler in *Striga* infested sorghum field in Sudan.

Three species of *Striga* account for most of the damage. *Striga hermonthica* attacks sorghum, millet and maize in a broad band from Senegal in West Africa to Ethiopia in the east. *Striga asiatica* attacks sorghum and maize in Southern Africa, India, and even in the U.S. A small area of infestation in the Carolinas, discovered in the 1950's, has been contained but not eliminated. Another species, *Striga gesneroides*, attacks cowpeas in West Africa. All are deservedly called "witchweed".

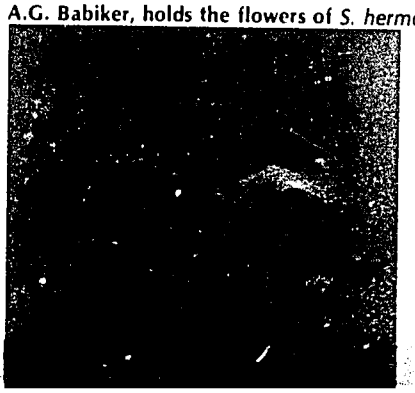
Research supported by INTSORMIL now offers hope that this devastating parasite can eventually be controlled. In contrast to almost all other plants, *Striga* depends completely upon another plant — its host — for signals which control its initial development stages. This dependency upon an external chemical stimulus should provide a means for its control.

By blocking or intercepting these signals, the *Striga* seed can be prevented from germinating or attaching to the host. Alternatively, providing external signals when no host is present can cause the *Striga* seed to commit to development and thus commit suicide.

INTSORMIL has made significant progress in a short time toward understanding and approaching a solution, but developing a practical way of exploiting *Striga's* vulnerability remains an extremely complex and difficult task. Much more research — supported by adequate funding — is essential.



Sudanese weed scientist, Dr. A.G. Babiker, holds the flowers of *S. hermonthica*.



Characteristics of *Striga*

Striga has so completely adapted to life as a parasite that it cannot survive in the absence of a host plant. Its rudimentary roots attach to those of the host plant and withdraw moisture, minerals and photosynthetic products such as sugars. Development of above-ground parts of the host plant is so severely reduced that it produces little or no grain. Much of the damage occurs before the *Striga* plant produces an above-ground shoot that the farmer can see, but the stunting and wilting effects on the host plant of the underground *Striga* are readily recognized. *Striga's* effects are more severe where moisture and fertility are limiting; these conditions prevail in most areas where sorghum and millet are produced.

Striga is an inefficient photosynthesizer. Even after developing a stem and green leaves, it continues to draw sugars as well as moisture and minerals from the host. *Striga* produces flower spikes (pink for *S. hermonthica*, the species most virulent against sorghum and millet) and eventually up to 50,000 seeds per plant. One host plant can be parasitized by up to 300 *Striga* plants, and *Striga* seeds up to 20 years old have been reported to be viable. The enormous populations of viable *Striga* seed contitute a formidable problem for host crops.

Striga seeds (top) compared to corn and sorghum. (from ICRISAT Bulletin No. 15)

Initial Host-Parasite Interactions

Although *Striga* is completely dependent upon its host plant, its development is so ingeniously adapted to its environment and integrated with that of its host that it can dominate its environment, especially when that environment consists only of cereals. The seeds will not germinate in the season in which they are produced; there would be insufficient time to produce another crop of seeds. The tiny (0.2 mm) seeds, barely visible to the naked eye, can survive independently only about four days after germination. They die unless they contact a host root within that time.

Germination occurs only 10 days or so after the beginning of rain during which potential host plants become established. Only those seeds germinate which are exposed to a chemical stimulant produced by the host plant roots. The requirement for this signal ensures that a suitable host is available and near enough to be reached by the miniscule *Striga* rootlet, which tends to grow toward the source of this signal. Most of the *Striga* seeds present in the soil are not reached by the stimulant and remain viable for subsequent crop seasons.

When the root tip of the germinating *Striga* seeds nears the surface of the host root it apparently receives a second chemical signal which causes the *Striga* root to stop elongating and to form a specialized attachment structure, the haustorium. After attachment, *Striga* tissue intrudes into the vascular tissue of the host root, eventually developing a direct connection for obtaining water, mineral nutrients and sugars. Secondary haustoria form at other sites, and other *Striga* seedlings attach so that eventually much of the host's root system is taken over by the parasite.

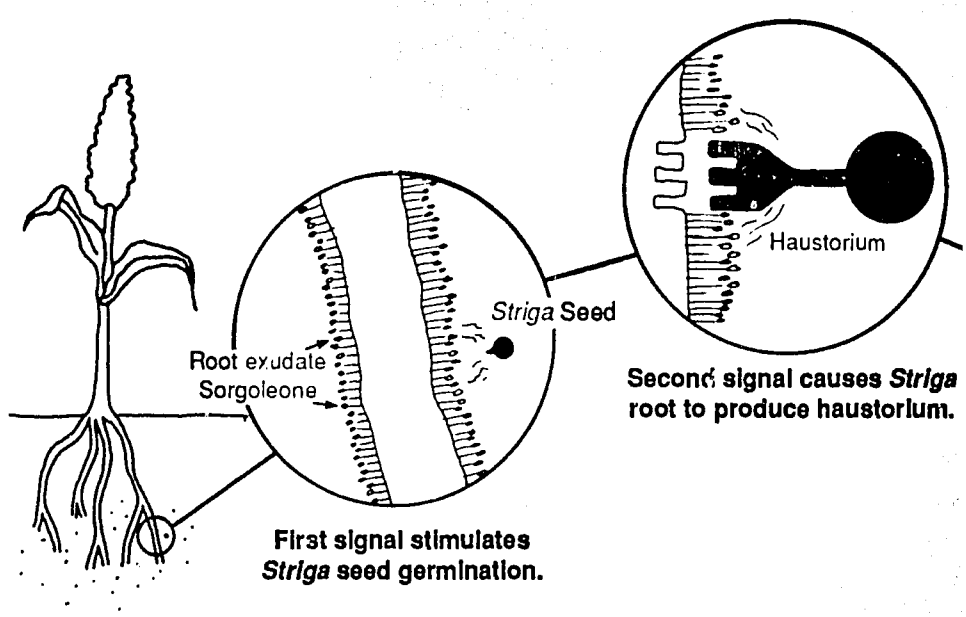


Diagram of *Striga*-host interchange of signals.

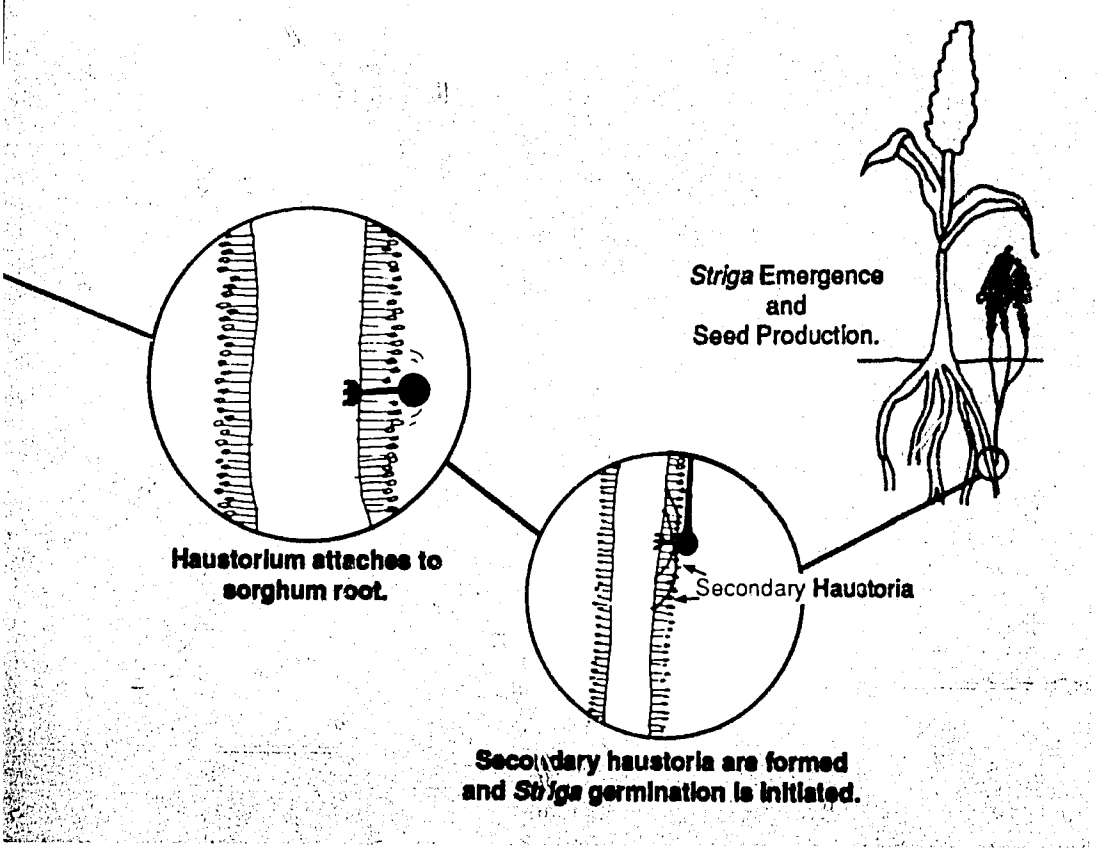
Keys to Control

In traditional cropping systems cereals were grown only intermittently on any particular piece of land, so *Striga* rarely developed the high seed populations associated with severe infestations observed under monoculture. More recently, intensive cropping of cereals year after year to meet the needs of increased populations has exacerbated the *Striga* problem. Herbicides do little to protect the current crop, but may be useful to prevent *Striga* from setting another crop of seeds. Most African farmers cannot afford herbicides, and although they are advised to pull the *Striga* plants by hand they cannot do so in large, severely infested fields. Again, this labor-intensive strategy is directed toward reducing the *Striga* seed population for future crops and has little effect on the current crop. No effective means of controlling *Striga* under African conditions is presently available.

The parasitic nature of *Striga* may be one key to its control. The host-produced germination stimulant and haustorium inducer are crucial signals which control the early stages of development of the *Striga* plant. Most plants produce their own development signals (plant growth hormones) so that they develop independently and continuously. *Striga's* unusual dependence upon its host plant for these developmental signals represents a unique vulnerability that may be exploited to gain control of this pernicious parasite. Interception or disruption of these early developmental signals could prevent *Striga* seed from germinating or attaching to the host root. Application of spurious signals could result in suicide by germination in the absence of the host or by haustorium development too far from the host root. Control of these signals should stop *Striga* before it damages the host crop, and might even make possible the cleanup of an infested field.

Numerous attempts since the 1930's to identify a *Striga* germination stimulant from a cereal host were not successful. It was suggested that the material is produced in trace amounts too small to characterize, and that it is unstable, rapidly losing its ability to stimulate *Striga* germination. From the roots of cotton, not a host for *Striga*, a germination stimulant was isolated and identified. This complex sesquiterpene, which was named Strigol, is apparently not produced by cereals. Its function in cotton is unknown, but it accounts for the effectiveness of cotton as a "trap" crop for *Striga*. Strigol causes germination of many *Striga* seeds so that a cereal grown the following year will be less infested with *Striga*. Unfortunately, cotton requires so much moisture that it cannot be grown in the major areas of sorghum and millet production.

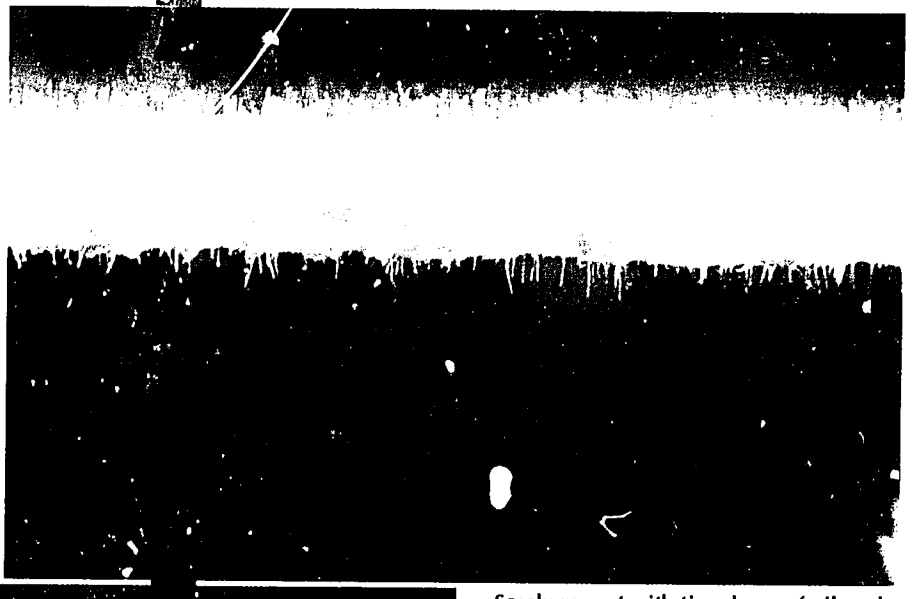
Efforts to synthesize Strigol for use as suicidal germination stimulants have produced active stimulants, but they could not be produced in adequate amounts at a reasonable price.



INTSORMIL-Supported Research

Striga Germination Stimulant from a Host Plant

Scientists at Purdue University are investigating the biochemistry of sorghum root exudate and the "chemical dependency" of *Striga* upon this material. Major collaborators on this INTSORMIL-supported project are Dr. Larry Butler, Dr. Abdel Gabbar Babiker of the Weed Control Unit, Agricultural Research Corporation, Wad Medani, Sudan, and Dr. Gebisa Ejeta of Purdue's Department of Agronomy. Dr. Ejeta's INTSORMIL-supported research on the inheritance of resistance to *Striga* in sorghum is very promising in its own right.



Sorghum root with tiny drops of oily yellow exudate on the tip of each root hair.

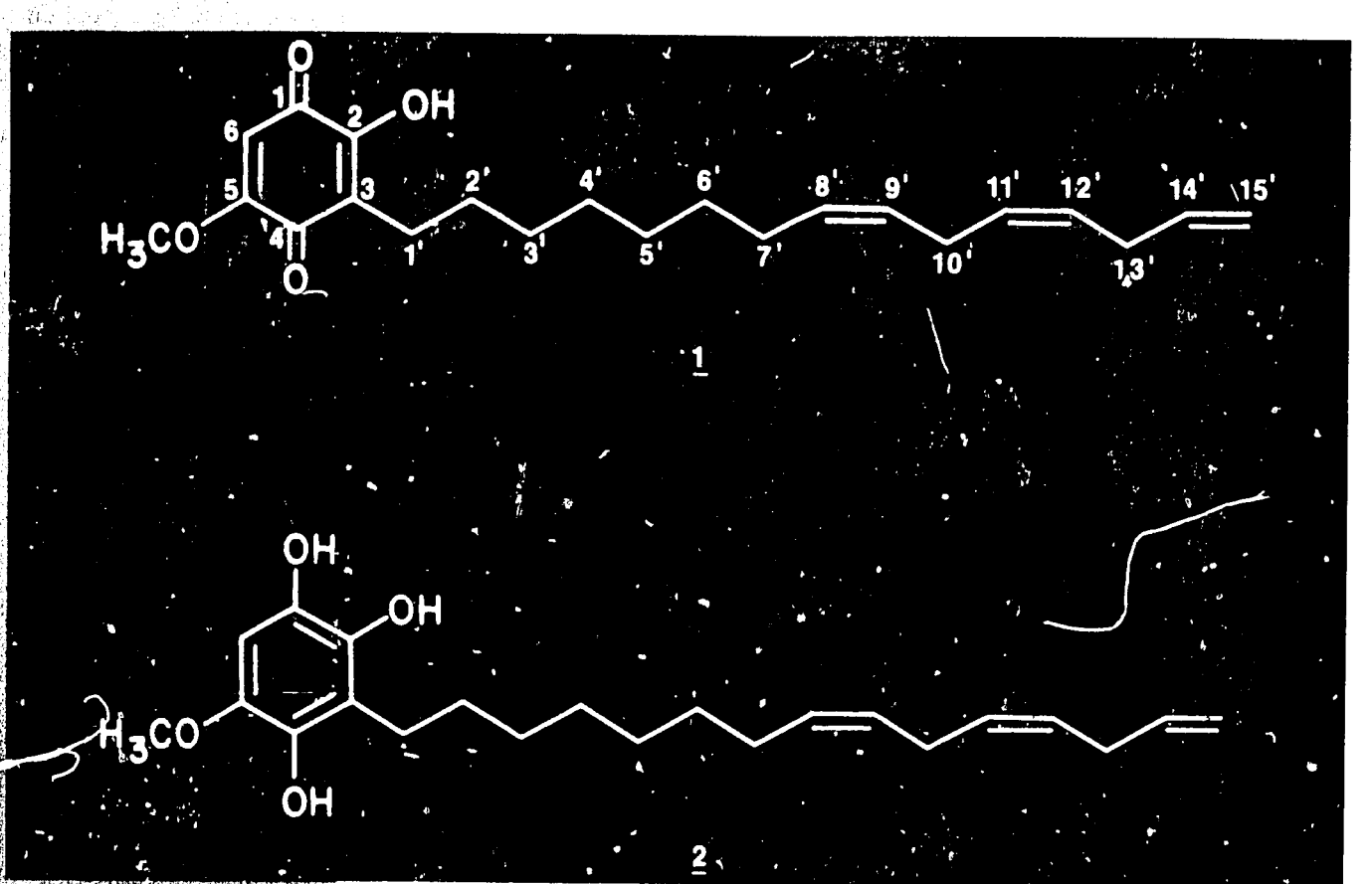
Oily root exudate extracted from these intact, regenerated sorghum plants proves that the sorgoleone must be produced by the plant itself and not by a contaminating organism.

The investigators have isolated a *Striga* germination stimulant from sorghum root exudate and have determined its structure, the first to be identified from a *Striga* host. These results suggest new approaches to utilizing modern biotechnology to control *Striga*.

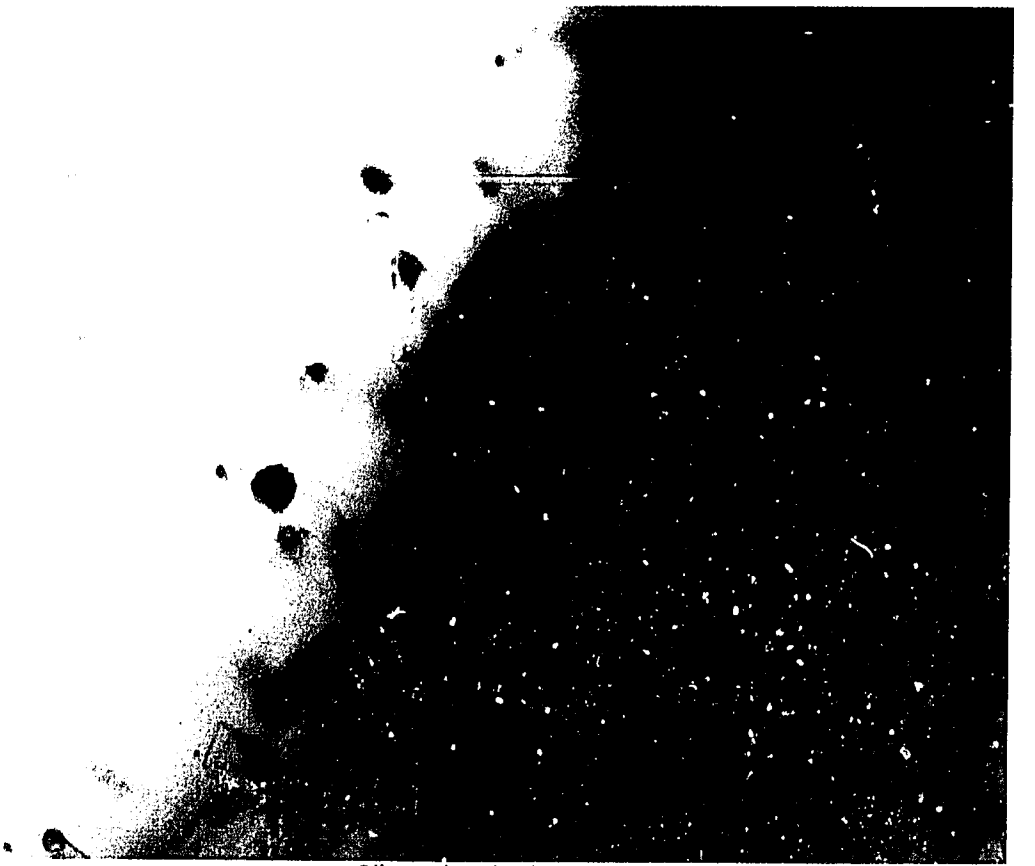
Dr. David Netzly, a postdoctoral fellow in the Purdue laboratory, observed droplets of oily exudate on the tip of sorghum root hairs. This material had not been previously reported so preliminary assays were carried out to determine whether it was active as a *Striga* germination stimulant. Because of quarantine restrictions, these and all subsequent *Striga* germination assays were carried out in the laboratory of Dr. J. Riopel at the University of Virginia. The oily exudate was found to be highly active as a stimulant of *Striga* germination, so this material was isolated, identified and characterized.

The chemical structure of the major component was determined with help from Dr. David Lynn of the University of Chicago. It is unlike any material previously reported from sorghum, although the simpler alkylresorcinols have been reported from the bran fraction of other cereals. Drs. Netzly and Butler characterized three minor components of the root exudate and found them to differ only in the number of double bonds or methylene carbons in the linear hydrocarbon chain. To these similar compounds they applied the collective name "sorgoleone", which refers to the source (sorghum), the major physical characteristic ("ole" in Latin for "oil") and the major reactive chemical group (quinone).

The form of sorgoleone which is active as a *Striga* germination stimulant is not a quinone, but a hydroquinone. The active hydroquinone is rather unstable and is readily oxidized to the inactive quinone form. This characteristic, along with its oily nature which makes it virtually insoluble in water, ensures that the active germination signal will reach only those *Striga* seeds which are very close to the host root. *Striga* seeds are so small that only those seedlings in close proximity to the host root have any chance of reaching it. These characteristics of sorgoleone make it an ideal host recognition factor and germination stimulant for *Striga* because its presence ensures that a suitable host is available and accessible, yet *Striga* seeds too far away are not stimulated to germinate and thus remain for subsequent seasons.



Chemical structure of sorgoleone. Quinone form (above) and hydroquinone form (below).



Oily exudate droplets stained with a reagent that detects quinones.

Other Activities of Sorgoleone

Compounds structurally similar to sorgoleone have been reported from other plants, although not from root exudates. These quinones and polyphenols are quite reactive chemically, and the alkyl substituent facilitates their interaction with cellular membranes. They exhibit a wide range of biological activities from insect antifeedants to anti-inflammatory agents, although the INTSORMIL scientists are not aware of any reported to stimulate or inhibit germination of any seeds. Nor have they found any other seeds where germination is influenced by sorgoleone.

Several of these compounds, and sorgoleone as well, are contact allergens. The itchy skin rash produced by sorgoleone is similar to that of poison ivy. Urushiol, the contact allergen of poison ivy, is structurally quite similar to sorgoleone.

Sorgoleone also has antibiotic activity, strongly inhibiting growth of certain bacteria. It almost certainly influences the population of microorganisms in the root environment. It appears to inhibit growth of the Rhizobium bacteria which fix nitrogen in nodules on the roots of legumes such as cowpeas. Because cowpeas are often intercropped with sorghum, further studies are planned to determine whether nitrogen fixation is impaired significantly by sorgoleone. Compounds similar to sorgoleone have been shown to cleave DNA; this could be the basis for antibiotic activity.

Sorgoleone strongly blocks root formation in some plants but has no effect on others. Pigweed *(Amaranthus)*, for example, simply cannot form roots in the presence of small amounts of sorgoleone. This selective herbicidal activity may protect sorghum against certain plant competitors.

Hydroquinones such as the reduced form of sorgoleone active as a *Striga* germination stimulant are capable of reducing ferric iron to the ferrous form more readily taken up by plants. It is possible that sorghum cultivars susceptible to iron deficiency may produce relatively low amounts of sorgoleone and thus be less susceptible to *Striga*.

These various chemical and biological effects are generally beneficial to the sorghum plant and thus possibly explain why sorgoleone production has not been eliminated by negative selection due to its harmful effect in stimulating *Striga* germination. *Striga* has developed resistance to this defense chemical of sorghum, and further has adopted it as a host-specific recognition factor. In a sense, *Striga* has turned sorghum's chemical defense against itself.

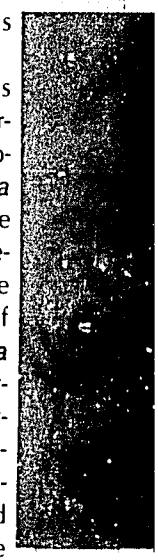
Technique for extracting sorgoleone from the roots of a sorghum plant.

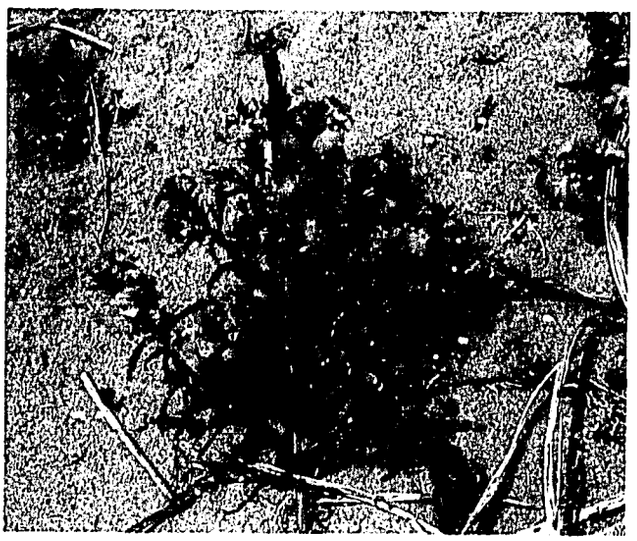
Potential Use of Sorgoleone or Other Developmental Signals to Control Striga

Plans are being drawn up for using the new information embodied in the chemical structure of host-produced developmental signals to develop new and effective approaches to the control of *Striga*. One of the early approaches will be the synthesis of modified sorgoleones with greater chemical stability and water solubility under field conditions. It might be possible to clean up infested fields by application of a germination stimulant in the absence of a host crop. Alternatively, it should be possible to develop *Striga* germination inhibitors based on inactive forms of sorgoleone. These might be applied as a crop seed treatment, delaying the germination of *Striga* and making possible the production of a crop in a field that is heavily infested with *Striga* seeds.

Another approach being considered is the development of sorghum cultivars which do not produce sorgoleone. All cultivars so far examined produce it. It is not clear whether sorgoleone-free cultivars would be less susceptible to *Striga*. Maize and millet produce water-soluble *Striga* germination stimulants rather than sorgoleone, and sorghum also may produce other water-soluble stimulants. These stimulants may be similar to the hydroquinone form of sorgoleone, but without the alkyl hydrocarbon substituent which prevents it from dissolving in water.

Other longer-term approaches under consideration involve characterization of sorgoleone receptor sites on conditioned *Striga* seeds, and identification of the genes that are activated in response to sorgoleone as well as the proteins coded by them. Studies of these early stages of *Striga* development, with clearly differentiable steps controlled by externally supplied signals such as sorgoleone, can make a unique contribution to basic plant biology, and may lead to other, more effective approaches to *Striga* control.



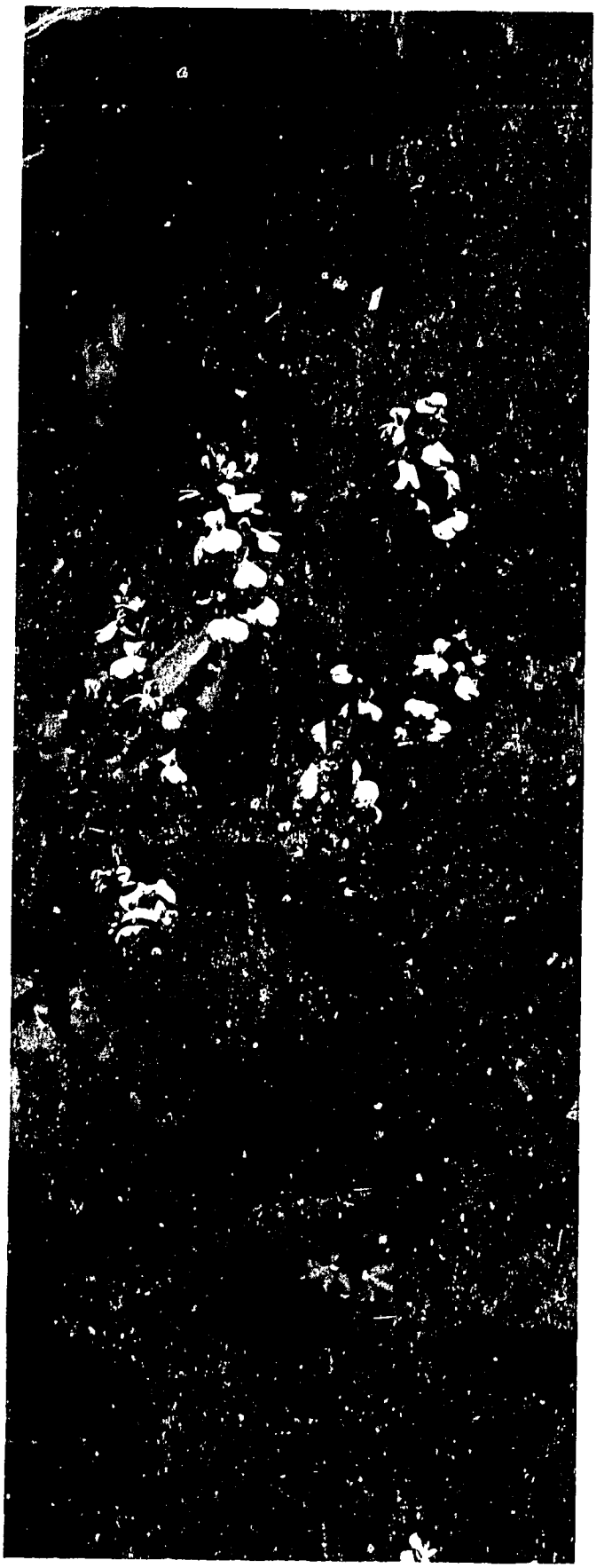


Top: INTSORMIL External Evaluation Panel (EEP) reviewing Niger *Striga* research, 1986.

Left: Clump of *S. hermonthica* parasitizing single sorghum plant.

Right: Single *S. hermonthica* plant closeup.

S. hermonthica in farmer's field, Niger, 1986.



A white flowered natural mutant of *S. hermonthica*.