PARASITIC WEEDS THREATEN FOOD SECURITY IN AFRICA

Fighting off rice vampires

A germinating seed (orange) of the parasitic plant Striga penetrates the stalk of its host. An electron microscope image.

Devastating parasitic weeds are doing millions of dollars' worth of damage to crops in sub-Saharan Africa. They drain their host plants dry like vampires. Researchers are doing their best to thwart these underground profiteers.

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Striga is a beautiful plant to look at. Bright, purplish flowers, vivid green stalks. But the rice field where this parasitic plant rampages is not such a pretty sight: stunted growth, shrivelled leaves, black spots on the crop... There won't be much of a harvest here.

Every year, African rice farming suffers about 200 million dollars' worth of damage from parasitic plants such as *Striga* and *Rhamphicarpa*, two plant genera of the broomrape family. Already, 1.34 million hectares of rice fields are affected, causing a loss of 15 million portions of rice per day, according to calculations by AfricaRice, the International Rice Research Institute and Wageningen University & Research.

'Without effective measures the economic losses will increase in the next few years by about 30 million dollars per year,' predicts international weed expert Lammert Bastiaans, a member of the Crops Systems Analysis chair group.

SUCKING DRY

So it is not just locust plagues and dust storms that wreak havoc on African agriculture. Parasitic plants are a serious problem too, especially in sub-Saharan Africa. 'They suck their host plants dry like vampires,' says Bastiaans. 'A host plant's growth is stunted, its leaves go yellow and it wilts. The plant thinks it is short of moisture due to drought and sends more and more nutrients to its root system. Parasitic plants cause harvest failures, hunger, poverty and rural depopulation. The pose an ever-increasing threat to food security in Africa.'

Bastiaans is the leader of an NWO-WOTRO research project in which seven Dutch and African research institutes have been collaborating since 2012 for a large international project called PARASITE. They are experimenting with measures to combat the devastating parasitic weeds in rice fields in sub-Saharan Africa.

'An infested rice field is soon overgrown'

SMELLING SIGNAL SUBSTANCES

The *Striga* plant genus includes 40 different parasitic plant species, some of which are unique to Africa while others grow in Asia and Australia as well.

Striga naturally grows on infertile soils. The semi-parasite gets its nutrients from the roots of other plants. Not just wild indigenous grasses but also rice, sorghum, millet and maize. It was calculated in 2009 that 40 percent of the land surface under cultivation in central Africa was infested with *Striga*, with damage running to billions of dollars a year.

Just one *Striga* plant produces between tens and hundreds of thousands of little black seeds which are spread effortlessly by water or wind, and which can survive in the soil for over ten years. The parasite needs a living 'host plant' in order to germinate and grow to adulthood. The seed only germinates once it can 'smell' from signal substances that there is a root of a suitable host plant growing nearby. Then a little root starts growing out of the seed towards the host plant root, boring into it with a specially formed suction organ, and sucking it dry.

Striga continues to grow underground for the first four to seven weeks, thereby cleverly escaping notice during the first round of weeding. By the time the parasite is detectable above the ground, the crop is often already lost. It is not called witchweed for nothing.

Bastiaans: 'Our project focuses on rice farming because rice is fast gaining importance as a food crop in Africa. And the problem of parasitic weeds in rice has been neglected for a long time.'

New varieties are being tested for resistance in field trials, says Bastiaans. 'And we are studying whether sowing earlier or later with faster-growing varieties could help. We are also experimenting with applying extra organic fertilizer, such as rice husks. Demo fields have been set up at agricultural research stations, so as to provide agricultural extension agents and farmers with advice.'

A lot of field research is going on in southwest Tanzania, which is plagued by both the main parasitic plant species affecting rice: *Striga* and *Rhamphicarpa*. In interviews, local farmers show they are well aware of the >

> **'The problem of parasitic weeds in rice has been neglected for a long time'**

Striga asiatica, indigenous to Asia and Africa.

problem, says Bastiaans. 'They spend a lot of time on weeding anyway. But the parasitic plants have often already done a lot of damage to the root system by then.'
While *Striga* mainly affects dry rice cultivation on somewhat higher, drier ground, the scourge of the paddy fields in the naturally wet lowlands is another villain of the broomrape family, *Rhamphicarpa fistulosa*, or vampire weed. This is an unsightly little weed which keeps its white flowers closed by day and, unlike *Striga*, germinates spontaneously. The tiny seedling grows very slowly, unless it happens to come across a root of a host plant. Then it goes into action, sucking out the root, growing much faster and producing much more seed than members of the species which lack a 'host'. 'This is known as a facultative parasite,' says Bastiaans. 'It can survive with or without a host plant, but thrives much better with one.'

SPREADING FAST

Throughout central Africa, this infestation is spreading extremely fast. Bastiaans: 'In recent years rice has become an interesting crop for Africa because more and more Africans are moving to the big cities and they prefer to cook rice as a convenient fast food rather than traditional, time-consuming sorghum.' Rice farming in Africa expanded by 33 percent between 2008 and 2014.
In the search for new farmland, many infertile, low-lying valleys, which are flooded in the rainy season and are therefore not suited to other crops, have been planted with rice. And it is precisely in these wet lowlands that *Rhamphicarpa* occurs naturally. 'The crop has been brought to the parasite. This kind of rice field is soon overgrown. And the parasite spreads from there. It is often carried by water, in which case you see the damage in broad bands across the lowest-lying part of the field. And if the farmers harvest their own sowing seed, it can already be infected by the miniscule *Rhamphicarpa* seed.'
The seed of *Rhamphicarpa* does not live as long as that of *Striga*, however. In a climate in which wet and dry conditions alternate, the seed is always swelling up and then drying out again. It stays good for two years at the most. With short-lived seed, the best strategy is an opportunistic one of taking a gamble on germinating and hoping you come across a host plant. You win some, you lose some. *Striga* seeds can afford to be a bit more patient, as they live far longer.

NO HARVEST

'Now that the demand for rice is increasing and farmers are clearing more fields for cultivation, infestations with *Rhamphicarpa* and *Striga* are increasing at an alarming pace,' says Tanzanian researcher Dennis Tippe, who works at the Uyole Agricultural Research Institute in Tanzania and is currently in Wageningen finishing off his PhD thesis. 'It is hugely frustrating for the farmers. Where there are serious infestations they harvest nothing at all. Young farmers in particular give up hope and migrate to the city. All the more so because our climate is changing: rain is coming later and is scarcer. Farmers are running out of options. Our population is growing but food production is not keeping up with it.'
Predominantly illiterate farmers from several different regions were asked at workshops what measures they adopt. This produced long lists, ranging from sowing extra early to crop rotation with potatoes or cassava. 'But the latter doesn't help much,' says Tippe, 'because *Striga* seeds survive for ten years. If you have to wait more than ten years before you can grow rice on the same field again, you won't get very far; rice is the main food crop. Crop rotation doesn't work as a weapon against *Rhamphicarpa* either; in the soggy lowlands there is simply a lack of alternative crops.'
The three most promising options were investigated further. At the research station in Tanzania, Tippe and his colleagues compared five different sowing times, at intervals of two weeks. 'In the case of *Rhamphicarpa* infestation, we see that sowing the rice earlier gives you a head start on the parasite. There seems to be less dam- >

PARASITIC PLANTS IN RICE CULTIVATION IN AFRICA

Parasitic plants pose serious problems for farmers, especially in sub-Saharan Africa. The most destructive of these are *Striga* and *Rhamphicarpa*, two plant genera of the broomrape family.

Striga

Striga naturally grows on infertile soils.

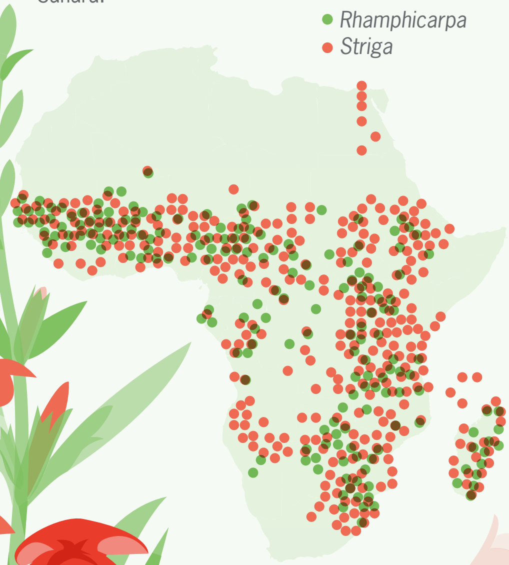
The small seeds of the *Striga* plant can survive in the soil for over ten years. They only germinate once they ‘smell’ signal substances from the roots of a suitable host plant.

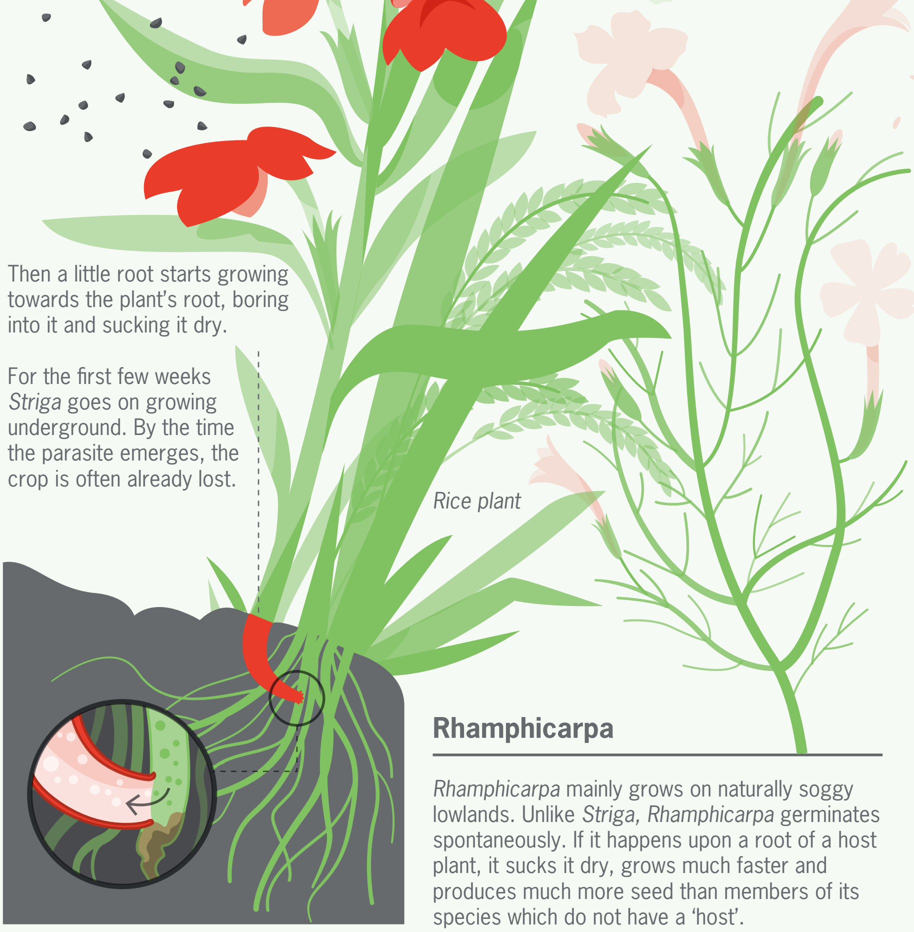
Then a little root starts growing towards the plant’s root, boring into it and sucking it dry.

For the first few weeks *Striga* goes on growing underground. By the time the parasite emerges, the crop is often already lost.

Prevention

The parasite is spreading like wildfire south of the Sahara.





Rhamphicarpa

Rhamphicarpa mainly grows on naturally soggy lowlands. Unlike *Striga*, *Rhamphicarpa* germinates spontaneously. If it happens upon a root of a host plant, it sucks it dry, grows much faster and produces much more seed than members of its species which do not have a ‘host’.

Damage

1.34 *m*
hectares of rice fields damaged

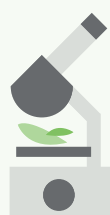
$ 200 *m*
annual damage

15 *m*
portions of rice lost every day

Approach

For *Rhamphicarpa* infestations, sowing the rice earlier gives the crop a bit of a head start on the parasite, and less damage is done.

For *Striga* infestations, sowing later can help. The *Striga* seeds come out of their dormant period at the beginning of January. If the seeds don’t detect any host plant roots in the vicinity, they go back to a dormant state, in which they remain for the rest of the season. Sowing the rice later enables it to escape the clutches of *Striga*. But it does have to be harvested before the end of the rainy season. And for that a faster ripening variety is needed.



New crops are also examined for resistance to Striga and Rhamphicarpa.


PHOTO GEBISA EJETA

A field full of *Striga* in bloom. The plant does a lot of damage to the crop and is almost impossible to eliminate.

age,' says Tippe. 'In *Striga* infestations on slightly higher, drier land, it is sowing later that can help because the *Striga* seeds come out of their dormant period after the first rain at the beginning of January. If they don't detect any host plant roots in the vicinity, they go back to a dormant state, in which they remain for the rest of the season.' So rice that is planted one month later escapes the clutches of *Striga*.
But it is vital to be able to harvest the rice before the end of the rainy season at the end of May, otherwise the crop suffers from drought stress before the grains have ripened. For this reason, a faster-maturing variety is required. Traditional African varieties of rice make a lot of leaves and side shoots, and mature in about 150 days. African consumers like their particular aroma, flavour and grain size, so rice farmers will not readily switch to other varieties. Another major consideration for the farmer is that such a leafy crop keeps the soil well covered, giving weeds less of a chance. Weeds are always a big problem for small-scale African farmers, who don't use chemical herbicides and spend a lot of time on weeding.

NEW VARIETIES

In the Tanzanian field trials, researchers are screening new varieties for resistance to *Striga* and *Rhamphicarpa*. These new varieties have been developed over the past ten years by the international research institute AfricaRice, a collaboration between 26 African countries. The varieties have sprung from cross-breeding highly productive Asian rice *(Oryza sativa)* and the leafy African rice *(Oryza glaberrima)*. They have been given the name NERICA, an acronym for New Rice for Africa, and they produce an excellent yield. Another big advantage for small-scale farmers is that they can produce their own sowing seed, and do not have to buy new sowing seed every year. Commercial plant-breeding companies often produce what are known as hybrid seeds. These are costly but perform very well in productivity terms, but the rice cannot be used as seed for next year's crop.
Because the problem of parasitic plants in rice was neglected for so long, resistance to them was not what the NERICA varieties were selected for, but there are natural differences in resistance between them. The trick now is to identify those differences in field trials under local conditions.
Tippe: 'We experimented with different varieties for three years. In the third year, participating farmers could try them in their own fields too. Precisely in that year there was a serious outbreak of *Striga*. This convinced a lot of farmers to start sowing later using new, resistant and faster-maturing varieties.'

GROUND COVER

The fast-growing, less leafy Asian *Oryza sativa* varieties which mature in 90 days have the disadvantage for African farmers, most of whom do not use herbicides, that they do not sufficiently cover the ground, giving weeds more of a chance. The most promising variety turned out to be one which matures in 120 days, does not leave much room for weeds but still has a head start on *Striga*

because farmers can plant it one month later.
Research has also been done on soil improvement measures such as using artificial fertilizer and livestock manure. In fertile soils parasitic plants are not a problem. Bastiaans: 'In follow-up research we want to find out exactly what the relationship is between better fertilization and improved crop health. If the crop grows better and more crop remains stay in the soil, you get a richer soil life and the parasitic seeds might more easily be attacked by micro-organisms and die off. And it is also possible that a well-fertilized plant's immune system functions better.'
A cheap option is to mix expensive artificial fertilizer with locally available organic material. But farmers do not want anything to do with livestock manure because after harvest the cows graze on the stubble and their manure is full of weed seeds. Another potential source of minerals is the rice husks which are left over after threshing. Using these has led to a slightly better rice harvest but has not had a convincing effect on the parasitic weeds.

> 'Parasitic weeds cause harvest failure, hunger, poverty and rural depopulation'

LOCATING VICTIMS

It is not just field researchers who are interested in parasitic plants. Plant physiologist Harro Bouwmeester has been doing research for about 20 years in Wageningen on the signal substances with which parasitic plants locate their victims. Two years ago he got an Advanced Grant of 2.5 million euros from the European Research Council (ERC). He had already won an NWO-VICI grant of 1.25 million euros ten years previously.
'The puzzling thing is that host plants excrete signal substances through their roots: strigolactones, which induce the germination of *Striga* seeds,' says Bouwmeester. 'At first we thought, rather naively, that the problem would be solved if you bred crops which no longer excreted strigolactones. But then it turned out that crops with strigolactones mobilize useful mycorrhiza fungi as well.' These fungi help plant roots to absorb water and nutrients in exchange for sugars, which the fungus needs in its turn. The fungal filaments increase the reach of the root system considerably. This makes the biggest difference in poor soils. Bouwmeester: 'It was discovered in 2008 that strigolactones play a very important role in the growth and development of the plant itself. They are plant hormones which suppress the formation of lateral shoots, making the plants less 'bushy'. It turns out that they determine the architecture of the root system too. On poor soils plants make more of these hormones, not just to stimulate the mycorrhiza fungi but also so as to invest less in growth above the ground and more in growth underground, to develop a larger and wider-spreading root system. And that is extremely useful. So breeding crops without strigolactones is not a good idea.'
Bouwmeester's group proved that crops which have access to more phosphate produce fewer strigolactones and are therefore less afflicted by *Striga*. 'But the poor African farmers have to be able to afford that artificial fertilizer.'

CROSS-BREEDING FOR RESISTANCE

Over the past couple of decades, plant breeders have been looking for compact, less leafy and highly productive types of rice which do not invest too much energy in extra leaves and shoots but get on with forming grains. But without realizing it the breeders may also have selected for types of plant with high levels of strigolactones, which then also wake up more parasitic weed seeds in the soil.
One of Bouwmeester's PhD students, Mahdere Shimels from Ethiopia, who is hoping to receive her doctorate this autumn in Wageningen, is studying strigolactones in sorghum. She is working with American colleagues who bred a sorghum variety which is resistant to *Striga*, with the support of the Bill & Melinda Gates Foundation. Bouwmeester: 'The Americans are now working on cross-breeding this characteristic into other sorghum varieties too, and meanwhile we are trying to figure out the underlying mechanism. Plants make a great many different kinds of strigolactones. In sorghum, for instance, there are about eight kinds, which are not all equally efficient at triggering the germination of *Striga*. We now think that resistance to *Striga* is not so much a question of smaller quantities of strigolactones as of a particular combination of them.'
Last year, in search of a new challenge, Bouwmeester moved from Wageningen to the University of Amsterdam, where he is now professor of Plant Hormone Biology. His work in Wageningen will be continued by Carolien Ruyter-Spira. 'Together, we are going to find out more about the biological importance of all those different strigolactones,' she says. 'Why are there so many of them? What determines their specific effects? Why does one parasite germinate better with one type of strigolactone, and another with a different one? And what is the genetic basis for this? With such knowledge, Dutch research can help African farmers.' ■

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