Biological Constraints to Increased Groundnut Production in the Semi-Arid Tropics

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Abstract

Groundnuts, wherever they are grown, are subjected to a wide range of destructive organisms that can reduce yields. Fungal pathogens are common, and on a global scale the leaf spots, rust, and the toxin-producing Aspergillus flavus *are regarded as important, and can drastically reduce yields or the quality of the crop. Other fungi are regionally or locally important, and there are instances where new pathogens have recently become serious. In general, viruses are restricted in distribution, but on a regional or national basis can be devastating in years when epidemics occur. At least one virus, the seedborne peanut mottle virus (PMV), is found in most groundnut-growing countries and is often overlooked because it produces mild symptoms. Only one bacterial disease, caused by* Pseudomonas solanacearum, *is economically important, and is a problem in certain areas, particularly China and Indonesia.*

Many pests attack groundnuts, but relatively few cause consistent and serious yield losses on a worldwide basis. Aphids are, however, important globally and are vectors of several important viruses. Direct yield losses caused by species of thrips are usually not serious, but Frankiniella schultzei *is very important as the main vector of bud necrosis virus in India. Locally, leafhoppers, millipedes, leaf miners, and various sucking bugs can be serious pests.*

Over the last decade there has been an increasing effort to utilize host-plant resistance, or integrated management schemes, to overcome many of the more serious yield reducers.

Aspects of poor nodulation due to inefficient native strains, or poor application techniques, are discussed in the light of current research findings.

Résumé

Contraintes biologiques à l'accroissement de la production d'arachide dans les régions tropicales semi-arides : *L'arachide, partout où elle èst cultivée, est soumise à une large gamme d'organismes destructeurs qui peuvent réduire la production. Les champignons pathogènes sont communs, et à l'échelle mondiale, les taches foliaires, les rouilles, et la toxine produite par* Aspergillus flavus *sont considérées comme importantes et peuvent radicalement réduire la production et la qualité de la récolte. D'autres champignons sont régionalement ou localement importants et il y a des cas ou de nouveaux agents pathogènes sont devenus récemment dangereux. En général, les virus ont une distribution restreinte, mais régionalement ou localement ils peuvent être dévastateurs durant les années d'épidémies. Un virus, au moins, le "peanut mottle virus" (PMV) porté sur les semences est présent dans la plupart des pays producteurs d'arachide; il est souvent sous-estimé parce qu'il produit des symptômes légers. Seule une maladie bactérienne causée par* Pseudomonas solanacearum *est économiquement importante et pose un problème dans certaines zones, particulièrement en Chine et en Indonésie.*

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De nombreux insectes nuisibles attaquent l'arachide mais relativement peu sont responsables de pertes de production graves à l'échelle mondiale. Les aphidés sont cependant importants car ils sont les vecteurs de divers virus importants. Les pertes de production directes causées par diverses espèces de thrips ne sont pas graves en général, mais Frankiniella schultzei *est très importante puisque c'est le vecteur principal du virus de la nécrose du bourgeon en Inde. Localement les cicadelles, les mille-pattes, les mineuses des feuilles et diverses cochenilles peuvent être des insectes nuisibles dangereux.*

Durant la dernière décennie, un effort important a été mené pour utiliser des plantes hôtes résistantes ou des schémas de gestion intégrée afin de combattre les principaux réducteurs de rendement.

Des aspects de faible nodulation dus à des souches originelles inefficaces ou à de mauvaises applications techniques sont discutés à la lumière de résultats de recherche récents.

Introduction

The cultivated groundnut, *Arachis hypogaea* L., is grown in many countries of the semi-arid tropics (SAT). In the SAT the groundnut, with its high protein and oil content, is important both as a human food and a source of cooking oil. Groundnut hay is used extensively in the SAT as cattle fodder, particularly in the dry season after the crop has been harvested. The hay is often sold for cash in Africa, but the yield and quality may be affected by foliar diseases which can cause extensive defoliation before harvest. To many farmers of the SAT, groundnuts are a major source of cash income when sold for local consumption, or for export to developed countries.

Yields in the SAT are low, averaging 800-900 kg ha^{-1}, compared to the average yield of over 2500 kg ha^{-1} produced in developed countries such as the United States. The low yields can be attributed to three major constraints: unreliable rainfall, pests, and diseases. In the United States similar constraints are present, but are overcome by capital inputs of mechanization, irrigation, fertilizer application and pest-control systems.

Biological constraints are not independent of abiotic constraints. Pests and diseases are affected by each other, and by climate and soils in very complex interactions. For simplicity, biological constraints can be conveniently discussed under the headings of diseases, insect pests, and factors affecting symbiotic relationships with nitrogen-fixing bacteria. In this review weeds will not be discussed, although their importance as yield reducers is well recognized.

Diseases

Groundnuts are affected by many diseases caused by fungi, viruses, and bacteria. Diseases may be distributed worldwide, or of only regional or restricted significance.

Foliar Fungal Diseases

Three foliar diseases exist worldwide and cause significant losses annually, particularly in the developing countries of the SAT. The leaf spots (early and late) have long been regarded as serious diseases of groundnut, while the third major disease, rust, has only been of worldwide significance over the last 15 years.

Leaf Spots

Early leaf spot, caused by *Cercospora arachidicola*, and late leaf spot, caused by *Cercosporidium personatum*, are probably the most serious diseases of groundnut worldwide (Jackson and Bell 1969). The diseases have often been collectively referred to as *Mycosphaerella* leaf spots, Cercospora leaf spots, brown leaf spots, peanut cercosporiosis, viruela, and tikka (Jackson and Bell 1969). Although both leaf spots are commonly present together, the intensity and severity of each disease varies over localities and seasons, and there can be both short- and long-term fluctuations in their relative proportions. Early leaf spot was the predominant disease in the southeastern United States from 1967 until 1976, but since then late leaf spot has become dominant (Smith 1984). In the groundnut-producing states of southern India late leaf spot is very severe, and early leaf spot is much less important (Subrahmanyam et al. 1980). In Nigeria, late leaf spot predominates in the low-rainfall areas of the north, but early leaf spot is more important in the higher-rainfall areas (D. McDonald, ICRISAT, personal communication 1985). In Malawi early leaf spot regularly causes most complete defoliation of the crop in the main producing areas (1000-1500 m elevation) of the central region. Late leaf spot is common in the low-altitude areas where it is hot and humid (Sibale and Kisyombe 1980). Late leaf spot is more important in the Casamance region of southern Senegal (Gautreau and De Pins 1980). In many countries of the SAT detailed information defining which leaf spot predominates, and the climatic conditions affecting spread of the diseases, is lacking. Care also has to be taken in identifying the leaf spot fungi by symptoms alone, as symptom expression is affected by cultivar and environment (Subrahmanyam et al. 1982a).

It has been estimated that leaf spots can reduce pod yields from 10-50% when fungicides are not applied (Jackson and Bell 1969). Losses of 10% have been reported in the United States, even under regular fungicide-application regimes (Jackson and Bell 1969). However many peasant farmers in the SAT cannot afford or lack access to modern fungicides, sprayers, and even adequate sources of clean water for high-volume spraying on their crop. In northern Nigeria application of fungicides in certain low-rainfall seasons has extended the growing season of cultivars adapted to the region, leading to drought stress and aflatoxin problems due to late harvesting (D. McDonald, ICRISAT, personal communication 1985).

There are at present no released cultivars resistant to either of the leaf spot fungi, but in the last few years more intensive research programs on breeding for resistance have begun in several countries. Breeding lines with moderate resistance to both leaf spots and with desirable agronomic traits are being bred (Smith 1984). Many rust-resistant cultivars, mainly from South America, also have moderate levels of resistance to *C. personatum* (Subrahmanyam et al. 1982b). Sources of resistance to early leaf spot in *A. hypogaea* have been reported from the United States (Sowell et al. 1976, Hammons et al. 1980). However, Subrahmanyam et al. (1983) failed to find resistance to early leaf spot in some 2000 genotypes screened in Malawi, even though the collection contained genotypes reported resistant elsewhere. Strains of both fungi resistant to the fungicide benomyl have been reported (Clark et al. 1974). Variation in the pathogens could make breeding for resistance more location-specific. Sources of resistance and immunity to the leaf spot fungi also occur in the wild *Arachis* species. Interspecific breeding programs utilizing this resistance are underway in the United States, and at ICRISAT Center in India (Stalker 1984, Moss 1980).

Rust

Rust, caused by *Puccinia arachidis*, was largely confined to South and Central America and the Caribbean prior to 1969, with occasional outbreaks occurring in the southeastern groundnut-producing areas of the United States. The disease was also recorded in the USSR in 1910, Mauritius in 1984, and the Peoples' Republic of China in 1937, but did not become permanently established in these countries (Hammons 1977, Subrahmanyam et al. 1979). In recent years rust has spread, and has become established in most groundnut-growing countries in Asia and Africa (Subrahmanyam and McDonald 1983). Yield losses from rust can be substantial. In Texas, Harrison (1973) reported losses of 50-70%, and in India Subrahmanyam et al.(1983) reported losses of 50%. When rust occurs in conjunction with the leaf spot fungi, yield losses can be even higher.

The reasons for the rapid spread of rust over the last 15 years are not clear. Groundnut rust can spread by long distance dissemination of urediniospores, by the movement of infected crop debris, or by the movement of pods or seeds surface-contaminated with urediniospores or infected crop debris. There is no reliable evidence of groundnut rust being internally seedborne (Subrahmanyam and McDonald 1983). Urediniospores are short-lived on infected plant debris. It is therefore unlikely that the fungus is perpetuated from season-to-season in crop debris under the hot climatic conditions often encountered in the SAT, particularly if only one groundnut crop is grown in a year (Subrahmanyam and McDonald 1982). Perpetuation could be in several ways. The pathogens could survive from season-to-season on volunteer groundnut plants. No authentic alternate host species are known outside the genus *Arachis* (Subrahmanyam and McDonald 1983). Continuous groundnut cropping without any break appears to be the most likely factor in the perpetuation of rust. This happens in the SAT regions of India, particularly in the southern states, where rainy-season crops are followed by crops grown on residual moisture and under irrigation (Subrahmanyam and McDonald 1983). Double cropping of groundnuts also occurs in the wetter, humid areas of China (Zhou et al. 1980) and Thailand (A. Patanothai, Khon Kaen University, Thailand, personal communication).

In the SAT areas of southern Africa rust was reported in March 1974 from Zimbabwe, and in Zambia and Malawi in 1975. It is also present in Mozambique and Tanzania. Cole (In press) in a recent review of the rust situation in southern Africa states that although the initial outbreaks caused concern, and the disease is now endemic to the region, serious outbreaks are now confined to specific groundnut-growing areas and it is sporadic in the rest of the production areas. Cole (In press) has related altitude and humidity to rust outbreaks. Where groundnuts are grown in Malawi below an altitude of 750 m rust is serious, as in the lakeshore areas of the country which all lie below 500 m. Similar situations occur in the lower altitude areas of Zimbabwe, Zambia, Tanzania, and South Africa. All these countries, except Mozambique, grow a single crop of groundnuts in a year. Planting is from Nov-Dec, and the main production areas are at altitudes above 1000 m. In southern Mozambique groundnuts are planted from Jul-Oct and the main crop in more northerly areas is planted in Nov-Dec. Cole (In press) suspects that spores are blown from southern Mozambique to the main growing areas which are planted later. This could explain the late development of infections even in the rust-prone areas of Malawi. In Zimbabwe also, rust appears only on isolated plants a month before harvest.

In West Africa, rust was first reported in Nigeria during October 1976. The disease was widespread but not serious in the northern states, and occurred only near harvest time. It was suspected that the arrival of rust was from the east (Fowler and McDonald 1978). In early 1977 rust was found on volunteer groundnuts at Mokwa, in the higher-rainfall riverine areas to the south. It appeared in Zaria in late August 1977, and later appeared further north in Kano and Bornu states. Fowler and McDonald (1978) estimated yield losses at not more than 5%. Salako and Olorunju (In press) later reported that rust is highly dependent on the amount and spread of rainfall. In the wetter, more southern areas, where the rains last from 7-9 months, this disease is serious and occurs regularly. In the drier, main production areas, it is not economically important. Sankara (In press) reported that rust appeared in Burkina Faso in 1977 and is economically important in the 1000-1100 mm rainfall zone, particularly when temperatures are low (19-25°C), and the relative humidity is high (80%). Gautreau and De Pins (1980) regarded rust as a potential, rather than an actual, threat to groundnuts in Senegal and introduced rust-resistant material as a precaution. If the observations on high rainfall and long season length are indeed well correlated with rust outbreaks, then the main production areas in the drier zones of the SAT are not going to be seriously affected by rust.

Excellent sources of resistance to rust exist b the cultivated groundnut and in wild *Arachis* species, with breeding programs underway in several countries to incorporate these resistances. Agronomically acceptable, high-yielding, rust- resistant cultivars may become available soon (Subrahmanyam et al. 1984). Present evidence indicates that resistance to rust is stable over widely separated locations in the Americas, India, and the Peoples' Republic of China (Subrahmanyam et al. 1983).

Other Foliar Diseases

Many other foliar diseases caused by fungi have been reported from the SAT and other regions of the world. They are usually of local or of no economic importance at present, and they have been reviewed recently by Porter et al. (1984). Sometimes these diseases may become important if changes occur in cultivars or climate. Web blotch, caused by *Pho arachidicola* is also known as Ascochyta leaf sp and muddy spot. This disease was first recognized in the USA as serious in 1972, although described earlier in several other countries (Smith 1984). It has also become more important recently in Malawi and Zimbabwe, particularly during cool and wet seasons in the higher-altitude areas. In Zimbabwe breeding for resistance has begun after promising resistant cultivars were identified (Hildebrand 1980).

Soilborne Diseases

Two recent reviews list up to 20 soilborne diseases affecting groundnuts (Porter et al. 1982, 1984). Stem rot, caused by *Sclerotium rolfsii*, also known as white mold or stem blight, is listed as the most important yield-reducing disease in the United States. It has been recorded in all groundnut-growing areas of the world (Feakin 1973), but has not received or been given much prominence in the SAT. This is no surprising because rapid disease development requires warm, moist conditions, particularly under a very extensive, lush canopy. Mercer (1978) reported *S. rolfsii* as being a disease seen on research stations in Malawi, and Rothwell (1962) mentions the fungus as causing slight damage in Zimbabwe which could become more serious under intensive cultivation. The fungus overwinters on organic matter in the soil. At ICRISAT Center the disease is serious on groundnuts grown on Vertisols but not on Alfisols. Control measures include deep burial of crop residues by ploughing.

l Breakdown and Pod Rots

Many fungi attack pods, but two fungi, *Pythium myriotylum* and *Fusarium solani*, are responsible for serious economic yield losses in many countries (Porter et al. 1982). They have been studied intensively in the United States but little research has been done on them in the SAT. Mercer (1977, 1978) described *F. solani* as causing a wilt and pod breakdown in Malawi. Yield losses caused by these, and other similar fungi, have probably been underestimated in the SAT. At ICRISAT Center detailed studies have shown that susceptible cultivars had 20-25% of their pods rotted at harvest time. Disease levels in germplasm lines ranged from 4-72% (Subrahmanyam et al. 1980).

Macrophomina phaseolina causes a dry root rot, a stem rot, wilting, and 'blacknuts'. The disease is cosmopolitan and soilborne. *M. phaseolina* is particularly serious in the Gambia. Intact pods and seeds may appear healthy but if climatic conditions are favorable for fungal growth, or the harvest is delayed, blacknut symptoms occur. Infection starts between the cotyledons and eventually the white mycelium turns gray and then black. The symptoms are often hidden and become apparent only when the seed is split open. Apart from appearance, the quality of the seed is spoiled, making them unsaleable (Feakin 1973).

Seed and Seedling Diseases

Groundnut seed and seedlings are highly susceptible to disease because they present a rich source of stored nutrients useful to numerous fungi. If the delicate testa, which protects the seed against invasion by fungi, become damaged then the underlying cotyledons become susceptible to attack. Species of *Rhizopus* and *Penicillium*, *Aspergillus niger* and *A. flavus* are commonly isolated from germinating seed. Adverse soil temperatures and moisture conditions delay seedling emergence, and increase the probability of invasion by pathogenic soil inhabiting fungi (Sullivan 1984).

Aspergillus niger causes a crown rot and a collar rot as well as a seedling blight, and is a worldwide problem. It is very prevalent on the lighter tropical soils in the SAT because it can tolerate low soil-moisture conditions. It develops most rapidly at 30-35°C (Feakin 1973).

Many countries in the SAT have developed control measures for seed and seedling diseases, usually involving rotations and chemical seed dressings. Without these measures losses caused by *A. Niger* have been estimated at more than 50% in areas of continuous groundnut cultivation in India (Chahal et al. 1974).

Yellow Mold and Aflatoxin

Mycotoxins of *Aspergillus flavus* came into prominence in the early 1960s when they were found in groundnut meal, and killed 100 000 young turkeys in the United Kingdom. Mycotoxins are toxic fungal metabolites and the toxin produced by *A. flavus* group of fungi are known as aflatoxins. They are powerful carcinogens and have been implicated in both animal and human deaths from liver cancer (Pettit 1984). This discovery has caused great consternation among world health authorities and importers or users of groundnut products. The literature on *A. flavus* is now voluminous and has recently been reviewed by Diener et al. (1982).

As the role of the environment on the incidence of aflatoxin is discussed by two other scientists at this conference (Picasso and Pettit) only some general remarks are made in this review of biological constraints.

A. flavus is found throughout the world. In the SAT the groundnut crop is very vulnerable to invasion before harvest because pods are commonly damaged by insects and fungi, which facilitates invasion by *A. flavus*. As the crop is grown mostly by small farmers, often using hand tools, there is a high possibility of damage to pods and seeds at lifting and shelling. There is always a great chance of droughts occuring in the SAT, and droughts have been strongly linked with the occurrence of aflatoxin in groundnuts. Rapid drying of the seeds to 7-9% moisture content, below which levels the fungus cannot grow, is difficult in the SAT because drying is often done in the field. Late rains can rewet the pods and the moisture content rises, thus allowing the fungus to regrow. The SAT countries often lack the stringent inspection systems that have been set up in the United States, and moldy, infected seed is often eaten when the fields are gleaned after harvest. These overmature seeds are likely to have high levels of aflatoxin.

In addition to cultural methods, there are alternative approaches to reduce aflatoxin contamination. One of these is to breed cultivars with resistance to seed invasion by *A. flavus*. Several germplasm sources have been identified whose seed is not invaded by

A. flavus as long as the testa remains intact (Mixon and Rogers 1973, Mixon 1979, Mehan et al. In Press). Field trials in the United States with these breeding lines from Georgia failed, however, to show any reduction in aflatoxin content of their produce compared to the commonly grown cultivar Florunner (Blankenship et al. In press, Davidson et al. 1983). Another approach being taken at ICRISAT Center is to screen germplasm lines to determine the ability of their seed to support production of aflatoxin when inoculated with an aflatoxin-producing strain of *A. flavus* (Mehan et al. In press). Initial screening took place in 1979, and significant differences in the rate and accumulation of aflatoxin between cultivars were found (Mehan and McDonald 1983). Further studies have shown that the genotypes U4-7-5 and VRR 245 produced less than $10 \mu g\ g^{-1}$ seed of aflatoxin B_1 compared to the control cultivar TMV 2, that produced more than $150 \mu g\ g^{-1}$ seed. These genotypic differences in aflatoxin B_1 production were consistent over seasons, although levels were slightly lower in seed from the rainy-season crop than in seed produced in the irrigated postrainy-season crop (Mehan et al. In press).

So far no cultivar has been found that resists invasion when the testa is intact, and is also a low aflatoxin producer when the testa is removed. Attempts are now being made at ICRISAT Center to breed genotypes with low aflatoxin-production levels and resistance to seed invasion.

The solution to the aflatoxin problem will not be dependent on any one approach, whether it be genetic, cultural, or chemical. There will have to be an integrated management approach including good husbandry, correct harvesting and curing practices, good storage methods, genetic character utilization, improved sorting procedures, and detoxification techniques.

Bacterial Diseases

Bacterial wilt, caused by *Pseudomonas solanacearum*, is regarded as the only serious bacterial disease of groundnuts and is extremely serious on tobacco, potatoes, eggplants, and other solanaceous crops (Feakin 1973). Consistent heavy yield losses in groundnuts occur in the humid regions of southern China, Indonesia, and Uganda. Although a serious outbreak occurred in Georgia in 1931 it is now regarded as a minor disease in the United States (Gitaitis and Hammons 1984).

The disease flourishes in the warmer tropical and temperate areas. It is soilborne, and survives b soils with high moisture levels. At present it does not seem to constitute a threat to groundnut production in the SAT.

Virus Diseases and their Vectors

There are several virus diseases affecting groundnuts, many of which have not been precisely characterized (Reddy 1980). Four viruses are of particular economic importance in the SAT, and they differ widely in their distribution, characteristics, and mode of transmission. These four viruses have been more extensively studied than many of the minor ones, but there are still many gaps in our knowledge because of the lack of virologists and well-equipped laboratories in the developing world (Reddy 1980).

Peanut Mottle Virus

Peanut mottle virus (PMV) was first discovered as the causal agent of a mottle disease in 1961. Since then it has been reported in all major groundnut-producing regions of the world (Kuhn and Demski 1984). Positive identification of PMV has been made in the United States, East Africa, Australia, Europe, Japan, Philippines, South America, Malaysia, and India (Ghanekar 1980). It has probably not been identified positively in many other countries of the SAT because of the very mild symptoms produced, and the lack of plant stunting usually associated with viruses.

Yield losses have been estimated as high as 30% in Georgia, USA (Kuhn and Demski 1975). PMV is a polyvirus and is transmitted by several species of aphids, including *Aphis craccivora*, in a nonpersistent manner.

This virus occurs in nature on several important legume crops of the SAT, including *Glycine max, Phaseolus vulgaris*, and *Vigna unguiculata*. Transmission through groundnut seed appears to be the most important source of PMV in groundnut, and the free exchange of seed around the world has probably helped to spread the virus. Aphids are efficient vectors of PMV, and will transmit the virus to other plants. Any climatic conditions that favor a rapid buildup of aphid populations could result in an epidemic. The epidemiology of the disease has been studied in the United States (Kuhn and Demski 1984). Little is known about the role of wild legumes in the SAT that could sustain the virus, and the aphid vectors, during the dry season.

Tomato Spotted Wilt Virus

A ringspot disease caused by Tomato Spotted Wilt Virus (TSWV) was first reported in Brazil in 1941 (Costa 1950). It was subsequently recorded in South Africa, Australia, United States, India, and Nigeria (Reddy 1984a). The disease has only reached epidemic proportions in India, and this has only happened in the last two decades. It is now regarded as one of the most important groundnut diseases in India where it is known as Bud Necrosis Disease (BND), because one of the typical symptoms is death of terminal buds (Ghanekar et al. 1979). The virus has a wide host range, including some common weeds of groundnuts in India, and unlike PMV, it is not seedborne.

Over 7000 germplasm lines have been screened at ICRISAT Center for resistance, but without success. Some germplasm lines and a number of released cultivars do, however, show lower-than-average incidence of the disease under field conditions (Reddy et al. 1983). The disease is transmitted in India by two species of thrips, *Frankliniella schultzei* and *Scirtothrips dorsalis.*

The virus is only acquired by the vectors in the larval stage. Adults cannot acquire it but they can transmit (Reddy 1984b). Studies in India by Amin and Mohammad (1980) have shown that epiphytotics are associated with an abundance of the major vector, *F. schultzei.* Populations of the vector are at their lowest during the summer months when they survive on wild plants, cultivated crops, and ornamentals. Migration occurs after the monsoon showers start. At Hyderabad large-scale migrations to groundnuts occur in August and January. The thrips are carried by the prevailing winds, mainly in the early evening. Disease incidence is associated with immigrant thrips and secondary spread seems to be less-important (Amin and Mohammad 1980).

Control measures include early planting to promote plant growth before the major immigrations occur, and high plant populations to dilute the percentage of infected plants. Planting less-susceptible cultivars, such as Robut 33-1, is also a part of the integrated management system.

BND has become more important in India over the last decade, and this is possibly due to double cropping of groundnuts and planting highly-susceptible cultivars. Further research on the epidemiology of the disease on a national scale is required. As this disease can build up rapidly, vigilance should be exercised in other countries where the vectors and the virus are known to occur.

Peanut Clump Virus

Peanut clump virus (PCV) has been reported from Senegal, Burkina Faso, and the Ivory Coast in West Africa (Thouvenel et al. 1976), and from several locations in India. Early-infected plants in India produce few pods and yield losses of up to 60% have been observed in late-infected plants (Nolt and Reddy 1984).

The disease occurs in patches in the field, and reappears in progressively enlarged patches in later years. Infected plants are dwarfed and dark green with darkened roots, the epidermal layers of which peel off easily. The physical properties and morphology of the rod-shaped particles of West African and Indian PCV-isolates are identical. Local lesions produced by the Indian and West African isolates are identical on *Chenopodium quinoa*, but the West African isolates have a wider host range. Serologically, the isolates from within different regions of India are different (D.V.R. Reddy, ICRISAT, personal communication).

PCV is soilborne, and the vector in West Africa is a fungus, *Polymyxa graminis.* In India, the vector for PCV has not yet been confirmed, but P. graminis has been isolated from graminaceous hosts in PCV-infected soils (D.V.R. Reddy, ICRISAT, personal communication).

PCV is the first soil-transmitted virus to be identified in groundnuts. The actual distribution of PCV has not yet been fully determined in either West Africa or India. Visual observations of plants infected with PCV could be confused with the symptoms of 'green rosette', which is common in West Africa. The only control method at the moment is the use of biocides that destroy the soilborne vector, and hence the virus.

Groundnut Rosette Virus

Groundnut rosette, first reported from Africa in 1970, is recognized as the most economically important virus disease of groundnuts. It is now believed that rosette is confined to the African continent, south of the Sahara. Earlier reports of rosette in Australia and Indonesia were not substantiated, and in India the reports were based only on visual symptoms (Gibbons 1977). Several of the Indian reports probably confused clump and bud necrosis viruses with rosette (D.V.R. Reddy, ICRISAT, personal communication).

'Green rosette' (GGR) and 'chlorotic rosette'

(GCR) are recognized on the basis of symptoms. GGR is commoner in West Africa, whereas GCR is commoner in East and Southern Africa. Depending on time of infection the disease can cause yield losses of up to 80%. Rosette is transmitted in a persistent manner by *Aphis craccivora* (Reddy 1984c). Recent research has confirmed earlier reports that rosette virus consists of at least two components, one of which causes the symptoms of rosette, and the other is an assistor virus that is required for transmission by aphids (D.V.R. Reddy, ICRISAT, unpublished).

Limited tests have shown that no naturally-occurring hosts of the aphid, apart from groundnut volunteer plants, are alternate hosts of the virus as well (Gibbons 1977). In Tanzania, Evans (1954) stated that groundnut volunteers can survive the dry season and act as reservoirs of the virus and the aphid. In Malawi, volunteer groundnuts are difficult to find after the long dry season of 7 months begins in April (K.R. Bock, ICRISAT, personal communication). In Nigeria, Booker (1963) found that a weed, *Euphorbia hirta* was the principal host of the aphid, but not the virus, during the dry season. He also noted that in Nigeria the incidence of rosette increases from north to south, and is lowest in the comparatively dry Sudan zone where the bulk of the crop is grown. However, in 1975 a rosette epidemic occurred in the main-production, drier, zones of the country, not in the high-rainfall areas where it is usually endemic, but in the Sudan zone (Yayock et al. 1976). Out of an estimated 1.3 million ha planted to groundnuts in 1975, about 0.7 million ha were severely damaged at an early growth stage. Yayock et al. (1976) believed that an unusual combination of weather and sowing dates led to this disaster. Early sowing of groundnuts in the south was followed by dry weather after germination. Aphid colonies on these plants in the south developed many winged adults, which were blown northward by the prevailing winds, and reached the northern zones where the crop was just emerging. During subsequent dry weather in the north, winged adults were formed and dispersed to other areas. This led to a massive disease spread.

Resistance to rosette is available in germplasm from West Africa, and resistant cultivars have been bred in Senegal, Niger, and Malawi (Gillier 1980, Misari et al. 1980, Sibale and Kisyombe 1980). At the time of the 1975 epidemic in Nigeria all the resistant cultivars had been bred for the wetter, longer-season rosette-prone areas of Nigeria and they were not adapted to the Sudan zone. More detailed studies on the epidemiology of rosette are now being carried out in Nigeria and Malawi conjunction with the Peanut CRSP, Ahmadu Bello University, and ICRISAT.

Nematode Diseases

The groundnut plant is attacked by a variety of plant parasitic nematodes. In some areas of the world cultivation of the crop cannot be maintained without nematode control. Depending on the genus of nematode involved, root systems, pods, and seeds may be directly damaged. Affected plants lack vigor and have reduced drought resistance. Nematode damage can also affect nodulation and make the plant more vulnerable to invasion by diseases (Porter et al. 1982).

The root-knot nematodes (*Meloidogyne* sp.) are probably the most important in limiting groundnut yields (Porter et al. 1982, Rodriguez-Kabana 19[illegible]). *M. arenaria*, *M. hapia*, and *M. javanica* are distributed in all parts of the world between latitudes 35° N and 35° S. Other important cosmopolitan nematodes are species of *Pratylenchus*, *Aphelenchus*, and *Aphelenchoides*.

Many attempts have been made to find sources of resistance to nematodes in groundnuts. Particular attention has been paid to the species of *Meloidogyne*, but no resistance has been found so far (Porter et al. 1982), thus chemical control of nematodes is commonly undertaken in the United States. In the SAT, Germani (1979) has demonstrated dramatic pod and hay yield increases with nematicide treatments in Senegal to control *Scutellonema cavenessi*. Some of the chemical treatments also had very significant residual effects. In India, a parasitic nematode, *Tylenchorhynchus brevilineatus*, was shown to be the cause of a disease that had become known as 'Kalahasti Malady' in farmers' fields of Andhra Pradesh, India. The disease had been seriously affecting groundnut yields on sandy soils since 1976 (Reddy [illegible] al. 1984). Yields were again significantly increased by the use of soil chemicals. Misari et al. (1980) have recorded at least 11 species of nematodes on groundnuts in Nigeria, but consider that only two species may be potentially important. Due to the lack of trained nematologists in the SAT, damage caused by nematodes has probably been underestimated. Furthermore, many of the nematicides are both costly and toxic, so it is unlikely that farmers would readily use them. More work needs to be done on finding nematode resistance in groundnuts, as has been successfully done in other crops.

Rthropod Pests

Smith and Barfield (1982) have listed more than 360 soil- and foliage-inhabiting arthropod pests of groundnuts. This large number is not unique, and Van Emden (1980) considers this large diverse array of pests as typical of legume crops. Fortunately most of them are not serious pests, and although some of them are cosmopolitan in distribution, many of them are restricted to certain areas. Many of the groundnut pests are also pests of other crops.

The arthropod pests can be generally grouped into two major divisions, those attacking the foliage, and those inhabiting the soil. In this review the major pests are discussed under these headings. Foliage pests are subdivided into those that consume the plant parts, and those that are intracellular feeders.

F liage Consumers

Most of the important foliage feeders are *Lepidoptera*. Serious pests in India include *Spodoptera litura*, *Aproaerema modicella*, species of *Amsacta*, and to a lesser degree, *Heliothis armigera*. Amin and Mohammad (1980) reviewed the Indian literature and concluded that *Aproaerema modicella* and species of *Amsacta* had been long recognized as pests of groundnuts, whereas *Spodoptera litura* and *Heliothis armigera* had only come into prominence in the last two decades. This is possibly due to the spread of groundnuts into new areas, and the expansion of groundnuts as an irrigated crop in the dry season. *Aproaerema modicella* is also listed as a pest in Indonesia, under the earlier name of *Stomopteryx subsecivella* by Feakin (1973). In Nigeria, Misari et al. (1980) only record various beetles that consume flowers as being important foliage feeders. Lepidopteran pests in Senegal include *Amsacta* sp., and *Spodoptera littoralis*, according to Gautreau and De Pins (1980). The two-spotted spider mite (*Tetranychus* sp) is widespread and can be important when groundnuts are grown in light, sandy soils that become drought stressed. Populations can build up rapidly, particularly if predators are controlled by insecticides (Campbell and Wynne 1980, McDonald and Raheja 1980).

It is generally agreed that groundnuts are most susceptible to defoliation from 70-80 days after emergence (DAE), and can in fact withstand preflowering and near-harvest defoliation without severe effects on yield (Smith and Barfield 1982). Therefore unless defoliators build up during the most susceptible period, there is little need to spray insecticides to control them. Low to moderate levels of resistance to several defoliators have been recorded (Campbell and Wynne 1980, Leuck and Skinner 1971, Rao and Sindagi 1974).

Intracellular Feeders

Intracellular feeders cause damage by removing sap, by injecting toxins, and most importantly by acting as vectors for plant pathogens, particulary viruses.

Aphids are generally considered more important as vectors of viruses than causing direct damage. Smith and Barfield (1982) list six aphid species as vectors of virus diseases. Undoubtedly *Aphis craccivora* is the most important of these, as it is a vector of rosette, peanut mottle, peanut stunt, and groundnut eyespot virus. *A. craccivora* is widespread throughout the groundnut-growing areas of the SAT. In India, where rosette does not occur, direct damage by *A. craccivora* has been recorded in northern India by Rai (1976). As a direct pest aphids cause leaf curling and stunted growth, and during droughts the plants may suffer stress due to loss of sap (Feakin 1973). Misari et al. (1980) also reported that high aphid populations in northern Nigeria result in wilting and death of the crop during periods of hot weather.

Seventeen species of thrips have been listed as pests of groundnuts by Smith and Barfield (1982). As with aphids, their most important role is as vectors of tomato spotted wilt virus (TSWV). *Frankliniella schultzei*, and to a lesser extent *Scirtothrips dorsalis*, are the vectors of TSWV on groundnuts in SAT India (Amin and Mohammad 1980).

Thrips rasp leaf tissues, particularly young leaflets in the terminal buds, and when fully opened, the leaves are malformed and puckered. Particularly heavy damage can result in defoliation. Some reports from SAT countries, where TSWV is absent or rare, state that thrips are serious pests of groundnuts. Feakin (1973) records *Caliothrips indicus* as a serious pest in south India, and *C. impurus* and *C. sudanensis* as pests in Sudan. Misari et al. (1980) mention that thrips are becoming more important in northern Nigeria. In Malawi the large-seeded cultivar, Chalimbana, appears to be very susceptible to damage by thrips and leaves of this cultivar are more malformed and puckered than other cultivars (R.W. Gibbons, ICRISAT, unpublished).

According to Smith and Barfield (1982), the detrimental effects of direct thrips feeding on yield have been very controversial for many years. Many recent reports from the United States have failed to identify increases following chemical control with insecticides. Hill (1975) has also questioned the economic importance of thrips control in Africa. There appear to be sources of resistance to thrips in both the cultivated groundnut and in wild *Arachis* (Campbell and Wynne 1980, Amin and Mohammad 1980). This would be useful as part of an integrated management system where thrips are vectors of TSWV because genetic resistance to the virus has not yet been found.

Leafhoppers, particularly species of *Empoasca*, are pests of groundnuts in many countries. Adults and nymphs suck sap from the leaves, and the leaves become burnt and yellowed at their tips, because of the toxic saliva injected into the plants. In India, *E. kerri* is the dominant species and can cause irreversible wilting in seedlings according to Amin and Mohammad (1980). *E. facialis* is important in many parts of Africa, while *E. dolichi*, the cotton jassid, is an important pest of groundnuts in Nigeria (McDonald and Raheja 1980). There is little information on the economic returns of using insecticides to control leafhoppers, but there are reports of good levels of resistance to the leafhoppers in cultivated groundnuts (Campbell and Wynne 1980, Amin and Mohammad 1980).

Soil Pests

Important soil pests of groundnuts in the SAT include termites, wireworms, and various insect larvae. McDonald and Raheja (1980) considered that termites and millipedes are the most important soil pests in Africa, but termites are not listed as pests of groundnuts in the United States by Smith and Barfield (1982). Feakin (1973) lists 16 species of termites as pests of groundnuts in the SAT and many drier areas of the world. The damage caused can be divided into those species that scarify the pods, and those that enter the plant in the root region and mine the stems and roots.

The pod scarifying termites include species of *Odontotermes*, *Microtermes*, and *Amitermes*. After scarification the pods become weak and more vulnerable to breaking and cracking, which facilitates invasion by *A. flavus* and other fungi (Feakin 1973). In Nigeria, Johnson and Gumel (1981) found that pod scarification was caused by *Microtermes lepidus*, and more damage was caused in the drier zones of the Sudan savanna than in the wetter Southern Guinea savanna zones. Scarification was also more common in dead plants which had been killed by termites invading the roots. In market samples, Johnson and Gumel (1981) found the numb scarified pods rarely exceeded 5% of the total p but over 85% of the seed from scarified pods was infected by the fungi *Macrophomina*, *Fusarium*, and *Aspergillus*.

Termites can be controlled by chemicals, but those that are most efficient are usually very toxic to humans, and also persist in the soil for many years. Feakin (1973) advocates repeated mechanical cultivation over years, the use of less toxic chemicals, mulching, and good crop husbandry as possible control measures. Amin and Mohammad (1980) reported cultivar differences in the numbers of pods scarified by soil-inhabiting termites in India. Newer methods of termite control are currently being investigated by entomologists in Britain. These methods are based on the control of the fungi which termites cultivate as sources of food in their nests (T. Wood, Tropical Development and Research Institute (TDRI), London, personal communication).

Millipedes are common pests in many parts of Africa (McDonald and Raheja 1980). Immature forms of the genus *Peridontopyge* feed on young pods and developing seeds in Nigeria. Misari et al. (1980) estimate that pod losses can be as high as 30% due to millipede damage, but attacks vary over years and locations in northern Nigeria. Gautreau and De Pins (1980) reported that millipede damage to seedlings and pods has increased in Senegal over the last few years. In the Sudan, Ishag et al. (1980) reported that damage at the beginning of the rains when millipedes appear in great numbers.

Various other soil pests are important in the SAT. White grubs (*Lachnostera consanguinea*), the polyphagous larvae of beetles, are particularly important in the northern states of India. In some of these areas farmers have been compelled to stop growing groundnuts because of white grubs (Amin and Mohammad 1980). White grubs are of minor importance in Nigeria (Misari et al. 1980) and Malawi (Mercer 1978). *Hilda patruelis*, a Hemipteran sucking pest, causes groundnut wilting in Malawi and Zimbabwe. Adults and nymphs live in association with black ants in earth tubes at the bases of the groundnut stems. Control measures include insecticides that kill the pest or the ants (Feakin 1973). Reliable economic threshold limits for *Hilda*, and many other pests, are lacking in the SAT.

Biological Nitrogen Fixation

Groundnuts form symbiotic associations with soil bacteria of the genus *Rhizobium*. The *Rhizobium* fecting groundnuts is a member of the cowpea-cross inoculation group that nodulates other legumes, including cowpeas. Most groundnut-growing soils of the world have sufficient numbers of rhizobia present to form nodules on the crop. It has long been known, however, that not all rhizobial strains are effective in fixing nitrogen in symbiosis with groundnuts.

In recent reviews (Cox et al. 1982, Ketring et al. 1982, Wynne et al. 1980, Nambiar and Dart 1980) many factors have been shown to affect both nodulation and fixation, including soil nutrient status, diseases, insect pests, soil moisture, light, temperature, cultivar, and intercropping with cereals.

Recent evidence has shown that it should be possible to select specific strains of *Rhizobium* that can effectively increase yields of specific cultivars even when they have to compete with local, inefficient, native strains in a range of environments and soil conditions (Nambiar and Dart 1980). One such strain, NC 92, which was collected in South America and isolated in North Carolina, has shown significant yield increases with two released Indian cultivars, Robut 33-1 and JL 24, over a number of sites and seasons (Nambiar et al. 1984). Strain NC 92 shows promise in Cameroon with the locally recommended cultivar, 28-206 (T. Schilling, USAID, Maroua, Cameroon, personal communication).

Wynne et al. (1980) also believe strains can be selected after they have shown broad adoption with a number of host genotypes, or single genotypes. They suggest that sufficient variability exists for selection and manipulation of host genotypes and strains to produce greater nodulation, and greater fixing potential.

Direct application of rhizobial cultures to seed is the most common method of legume inoculation. However, groundnut seed is very fragile and easily damaged. Furthermore seed is often treated with fungicides, which may be toxic to the rhizobial cells. Nambiar et al. (1984) have shown that liquid cultures of *Rhizobium* were best applied to the soil in a furrow, just prior to planting the groundnut seed. They suspected that many of the bacteria applied to the cotyledons before planting may be moved out of the root zone during germination. When placed below the seed the inoculant was able to compete better with native strains already in the soil. These results may explain why inoculation trials in the past have failed to show yield increases.

Looking Ahead

A great deal is known about the biology of many of the harmful organisms that reduce yields of groundnuts in the SAT. However, detailed epidemiological studies of many pests and diseases are lacking on a national level, and very few studies have been made on a regional or international scale. Plant scientists need much more assistance from agroclimatologists to study the effects of climate on insect pests and diseases, and to forecast epidemics.

More studies are needed on the economic threshold of pest control. The timing and types of effective pesticide applications must receive more consideration because of the economic plight of the small-scale farmers of the SAT.

Breeding for resistance to insect pests and diseases must be regarded as the most effective and economic method of reducing biological constraints. In the long term, multiple resistances should be sought according to the needs of the country or region. The ultimate goal would be to put together a package of practices involving resistances, good agronomy, and extension advice. It must also be remembered that biological constraints are not static. Vigilance is needed to watch for new problems that may arise, particularly if the farming systems change.

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