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Groundnut viruses and virus diseases: distribution, identification and control

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I. Introduction

The groundnut or peanut (*Arachis hypogaea*) is a very important legume crop of tropical and subtropical areas of the world. Considerable information has now been published on its virus diseases. In most groundnut-growing countries the major groundnut viruses have now been characterized, reliable and sensitive detection methods developed, and control measures worked out. Information on global distribution of most groundnut viruses is therefore available. Most reports of groundnut virus diseases that are based only on symptoms or on such properties of the viruses as thermal inactivation point and longevity *in vitro* are unreliable and have been excluded from this review. Scientists and administrators are aware of the importance of properly characterizing viruses as a prerequisite to the development of effective control measures, and so well equipped virus research laboratories have been established in many countries where groundnuts are grown. This permits more intensive work on economically important viruses, and in particular on the use of efficient methods for detecting seed-borne viruses which would otherwise elude plant quarantine controls. Effective control strategies are best based on knowledge of the viruses and their vectors.

This review provides information on all the currently known economically important groundnut virus diseases, including the symptoms they cause, and methods for their identification (Tables 1 and 2). Data to assist identification of several virus diseases that seem to be of minor importance at present are presented in Tables 3 and 4.

A. hypogaea, the cultivated groundnut, is generally referred to as peanut in North America. This usage of two common names has influenced the nomenclature of the viruses reported on *A. hypogaea*; those reported from America incorporate the term 'peanut', whereas those first recorded from other parts of the world generally incorporate 'groundnut' to designate the host. Names such as peanut mottle, peanut stripe and groundnut rosette are so well established in the literature that no attempt has been made to change them. Nevertheless, the reader should be aware that the nomenclature of a virus occurring naturally on *A. hypogaea* will depend on where it was first reported and upon the nationality and background of the author.

II. Peanut mottle potyvirus (PMV)

PMV is found world-wide (Kuhn & Demski, 1984) in cultivated groundnut. In field tests in the USA, crop losses caused by PMV range from 20 to 70% (Kuhn & Demski, 1975). In field tests in India susceptible cultivars suffered crop losses of up to 40% (ICRISAT, 1984). Because of its wide distribution and its potential to cause severe yield losses, PMV is considered to be of global economic importance.

1. Symptoms

A mosaic of irregular dark-green islands appears first on young quadrifoliate leaves. In older leaflets, mosaic symptoms are not obvious but mild mottling can be seen by transmitted light. In some genotypes, the lamina is depressed between the veins and the edges of leaflets are rolled upward. Plants are slightly stunted but do not show any other symptoms. Both numbers and size of pods from infected plants are decreased.

2. Diagnosis

Reddish-brown local lesions are produced in sap-inoculated leaves of *Phaseolus vulgaris* (cultivars Topcrop, Tendergreen or The Prince) (Kuhn, 1965). In *Pisum sativum* (several cultivars) the virus produces vein clearing followed by systemic mosaic.

Specific antisera for PMV are available from several sources. Serologically, PMV is distinct from other naturally occurring potyviruses in groundnut, such as peanut stripe, peanut green mosaic and groundnut eyespot viruses.

3. Transmission

PMV is readily transmitted by sap inoculation. It is transmitted in the non-persistent manner by several aphid species including *Aphis craccivora, A. gossypii, Myzus persicae, Hyperomyzus lactucae, Rhopalosiphum padi* and *R. maidis* (Kuhn & Demski, 1984).

Transmission in groundnut seed varies from none to 8.5%, depending on genotype, virus strain and environment. PMV is also seed-transmitted in mung bean and cowpea but not in soyabeans.

4. Control

Though many *A. hypogaea* genotypes have been tested, none was found to be resistant to infection by PMV. Some wild species of *Arachis* are however resistant to PMV, but their resistance genes have not been transferred to *A. hypogaea*. Infected seed appears to be the primary source of virus for crops so it is important to sow virus-free seed. Genotypes in which the virus is not seed-transmitted have been identified, and agronomically acceptable non-seed-transmitting, high-yielding breeding lines are available.

III. Peanut stripe potyvirus (PStV)

PStV has been recorded in most groundnut-growing countries in south and South-east Asia including China, India, Indonesia, the Philippines, Vietnam, Myanmar (Burma) and Thailand. It was introduced into the USA in the early 1980s and is now widely distributed (Demski & Lovell, 1985).

1. Symptoms

Isolates of PStV may differ in the symptoms they induce (Demski *et al.*, 1988; Reddy *et al.*, 1988b; Wongkaew & Dollet, 1989). The name peanut stripe virus was given to an isolate that induced discontinuous chlorotic stripes along the lateral veins of young quadrifoliate leaves. However, the commonest isolates cause irregular green blotching of younger leaflets, persisting as the leaflets age. An isolate that induces chlorotic rings surrounding the blotching of young leaflets was reported from Thailand and Indonesia (Fukumoto *et al.*, 1986). The most widely distributed isolate in China induces mild mottle symptoms (Zeyong *et al.*, 1983).

2. Diagnosis

All PStV isolates induce local lesions in *Chenopodium amaranticolor* and *C. quinoa* leaves. Unlike PMV, PStV does not infect *Phaseolus vulgaris* (cv. Topcrop).

PStV particles react strongly with antisera against the particles of black eye cowpea mosaic, clover yellow vein and soybean mosaic potyviruses. They do not react with PMV antiserum.

3. Transmission

Several aphids can transmit PStV, in the non-persistent manner. *A. craccivora* and *M. persicae* transmit PStV efficiently (J.W. Demski, personal communication).

The frequency of transmission in groundnut seed is influenced by the age of the plant at infection, its genotype, the virus isolate and environmental conditions at the time. PStV is usually transmitted to a greater proportion of seed than PMV. In laboratory tests, up to 30% of seed yielded

infected plants (Demski *et al.*, 1984; Prasada Rao *et al.*, 1989) whereas, in field conditions, 0.1 to 5% of plants are infected, depending on the various factors mentioned above.

4. Control

Though over 8000 *A. hypogaea* genotypes have been screened in the field, none was found to be resistant to PStV. Several wild *Arachis* species have been shown to be resistant and some derivatives of interspecific crosses between them and the cultivated groundnut are currently being screened.

Infected seed appears to be the primary source of PStV for crops. *A. hypogaea* genotypes showing very little seed transmission have been identified (Zeyong *et al.*, 1989) and are currently being used in a breeding programme to develop cultivars that combine this trait with good agronomic characters.

Since PStV is one of the most widely distributed viruses of groundnuts in South-east Asia, it is essential that seed being exported from these countries be thoroughly tested for the presence of this virus. PStV has not been reported from Africa or South America, and strict quarantine measures should help prevent entry of PStV into these regions. Guidelines recently formulated should ensure that only virus-free seeds are used in germplasm exchange (Frison *et al.*, 1990).

IV. Peanut clump furovirus (PCV)

Peanut clump is a soil-borne virus disease widely distributed in India (Reddy *et al.*, 1988a) and West Africa (Thouvenel *et al.*, 1988). Peanut clump is also thought to be present in several other Asian countries. The virus often infects crops when they are young; thus it can cause severe losses. Symptoms induced by PCV are similar to those of green rosette disease and it is likely that, in Africa, these two diseases have been confused.

1. Symptoms

Diseased plants commonly occur in patches in the field, and the disease recurs in these same patches in successive groundnut crops. Young quadrifoliates of PCV-infected plants initially show mosaic, mottling, and chlorotic rings. Older leaflets are darker with faint mottling. Diseased plants are conspicuously stunted and have dark-green leaflets. They may produce flowers but any pods formed are poorly developed. Plants infected at later stages of growth produce pods, but seed weights may be reduced by up to 60%.

2. Diagnosis

PCV has an extremely wide host range, including monocotyledons. *Chenopodium amaranticolor, C. murale, C. quinoa* and *Vigna unguiculata* are local lesion hosts. In *Phaseolus vulgaris* (cv. Topcrop) the virus produces veinal chlorosis or necrosis.

PCV occurs in several serologically distinct variants (Reddy *et al.*, 1985c; Nolt *et al.*, 1988), and a polyclonal antiserum produced for one variant usually does not detect others. However, homology in genomic sequences has been detected (Reddy *et al.*, 1985c) and a complementary DNA probe that can detect several PCV variants is currently being prepared.

The genome of PCV is two single-stranded RNAs with *M*r 1.83×10^6 and 1.36×10^6. The virus particles contain a single polypeptide species of *M*r 24 000.

3. Transmission

PCV has been shown to be transmitted by a phycomycete, *Polymyxa graminis*. The life cycle of this fungus in its graminaceous hosts has been studied (Ratna *et al.*, 1991). The virus is seed-transmitted at up to 11% in groundnut. PCV is also transmitted in seed of pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), and foxtail millet (*Setaria italica*). Thus, long-distance dispersal through seed of cereal crops is possible.

4. Control

PCV and its vector *P. graminis* can multiply in several graminaceous species commonly grown in groundnut-growing systems, and this makes it difficult to control the disease by crop rotation.

The transmission of PCV in groundnut crops in India is correlated with temperature. When temperatures are low ($<25^0$C), only negligible PCV incidence is recorded (Reddy *et al.*, 1988a). The high temperatures that prevail in India and in West Africa during the main groundnut-growing season (monsoon or rainy season) are conducive to natural virus transmission. High temperatures during summer in India followed by monsoon rains appear to break the dormancy of resting sporangia of *P. graminis*.

The incidence of clump disease can be reduced by applying soil biocides such as dibromochloropropane and furadan at nematicidal dosages. Nevertheless their application on small farms is unlikely to be economical (*Reddy et al.*, 1988a).

Soil solarization effectively reduces clump incidence in India; well cultivated soils are profusely irrigated and covered with two layers of a transparent polyethylene sheet for at least 70 days during the summer months (Reddy *et al.*, 1988a). Whether it is economical to adopt soil solarization on small farms and in countries where polyethylene sheets are relatively expensive has yet to be determined.

V. Groundnut rosette disease

Groundnut rosette was first reported from Tanzania (Zimmermann, 1907). Rosette has been reported also in other continents, such as India, but it is now clear that either bud necrosis or peanut clump diseases were erroneously identified as rosette disease (Reddy, 1988), and it seems that the disease is restricted to Africa south of the Sahara.

Rosette is by far the most destructive of all groundnut virus diseases in Africa. For example, the epidemic which occurred in 1975 in West Africa caused over US$ 250 million worth of crop losses in Nigeria alone (Yayock et al., 1976).

1. Symptoms

Three different types of rosette, chlorotic, mosaic and green, have been recorded in groundnut (Hayes, 1932; Storey & Ryland, 1957; Hull & Adams, 1968).

(a) Chlorotic rosette

This is prevalent throughout Africa. Younger leaflets first show faint mottling and all subsequent leaflets are pale yellow with green veins. Plants infected when young produce progressively smaller chlorotic, twisted and distorted leaflets, but if infected when older they show symptoms in only a few branches or the apical portion of the plant. Internodes are shortened and stems thickened, especially in plants infected when young. Flower production of early-infected plants is severely reduced.

(b) Mosaic rosette

This is recorded only in East and Central Africa. Younger leaflets show conspicuous mosaic symptoms. Later symptoms resemble those of chlorotic rosette. Stunting is rather less pronounced than for chlorotic rosette.

(c) Green rosette

This is known to occur only in West Africa and Uganda. Younger leaflets show mild mottling and isolated flecks. Older leaflets are reduced in size, show downward rolling and are not distorted. Plants are severely stunted and are darker green than healthy plants. Plants infected early with green rosette are stunted and resemble plants infected with peanut clump virus.

2. Causal viruses

The viruses that cause groundnut rosette disease have only recently been characterized.

The disease is caused by a complex of two viruses (Okusanya & Watson, 1966; Hull & Adams, 1968; Dubern, 1980; Reddy *et al.*, 1985a) and a satellite RNA (Murant *et al.*, 1988). One component is a mechanically transmissible virus called groundnut rosette virus (GRV). No virus particles have been reported for GRV but infected plants contain abundant infectious single-stranded RNA (Reddy *et al.*, 1985b). GRV is transmitted by *Aphis craccivora*, but only from groundnut plants that also contain the second component, called groundnut rosette assistor virus (GRAV), which is a luteovirus (Casper *et al.*, 1983; Reddy *et al.*, 1985a; Rajeshwari & Murant, 1988) and is not mechanically transmissible. GRV has an associated satellite RNA, which is dependent on GRV for multiplication and on GRAV for aphid transmission. GRAV causes no symptoms in groundnut; rosette symptoms are associated with infection by GRV but recent work has shown that it is the GRV satellite RNA that is largely responsible, different forms of the satellite causing the green and chlorotic forms of rosette (Murant *et al.*, 1988; Murant & Kumar, 1990). The satellite RNA is also needed for the GRAV-dependent aphid transmission of GRV (Murant, 1990) but its precise role is not known.

3. Diagnosis

GRAV: In immunosorbent electron microscopy tests (Casper *et al.*, 1983; Rajeshwari & Murant, 1988) GRAV particles reacted with polyclonal antisera to those of barley yellow dwarf, bean leaf roll, beet western yellows, potato leaf roll and tobacco necrotic dwarf luteoviruses. Three monoclonal antibodies produced for potato leaf roll virus particles also reacted with those of GRAV (Rajeshwari *et al.*, 1987).

GRV and satellite: GRV cultures, with or without the satellite RNA, produce chlorotic lesions, about 1 mm in diameter, in *Chenopodium amaranticolor* leaves. In *Nicotiana clevelandii* necrotic rings are produced on inoculated leaflets followed by systemic symptoms, characterized by curled and distorted leaflets. *N. benthamiana* is the most sensitive test plant, inducing mild veinal chlorosis or necrosis on the first systemically infected leaves, followed by a faint mottle and moderate stunting.

Three major double-stranded RNA species of 4.6 kbp, 1.3 kbp and 900 bp were consistently observed in extracts from infected leaves analysed by electrophoresis in acrylamide gels. The 900 bp dsRNA was shown to be a satellite RNA (Murant *et al.*, 1988).

4. Transmission

The viruses associated with all three types of rosette disease are transmitted efficiently by *Aphis craccivora* in a persistent or circulative manner. By analogy with other similar virus complexes it is suspected that the genome and satellite RNAs of GRV are encapsidated in GRAV coat protein for aphid transmission. In field-infected plants at least two types of particle are likely: GRAV nucleic acid encapsidated in GRAV coat protein, and GRV and its satellite encapsidated in GRAV coat protein.

5. Control

Infected plants, especially those of green rosette, survive longer than comparable healthy plants. They are normally not harvested and these 'groundkeepers' may be an important source of inoculum. Additionally, 'self-sown' or 'volunteer' groundnut plants that survive though the dry season are also expected to provide the primary source of inoculum. Alternative hosts of the virus and the vector must exist in Africa, but these sources have not so far been identified (Gibbons, 1977; Reddy, 1984). It is likely that viruliferous aphids disseminated by the moving rainfall fronts are responsible for early infection (Davies, 1972). Both alate and apterous aphids are involved in secondary spread (Gibbons, 1977).

The disease can be effectively controlled by adopting the following cultural practices.

a) Destroy groundkeepers and self-sown groundnut plants after harvest of the main crops.

b) Sow early in the season and at high density.

c) Apply aphicides at the correct time (Davies, 1975).

Several rosette-resistant groundnut cultivars, all late-maturing, are now available. They were bred from germplasm accessions collected from the border regions of the Côte d'Ivoire and Burkina Faso and include RG1, several RMP cultivars such as RMP 41, 48, 91, 93, and RRI/6, RRI/16 and RRI/24. These resistant cultivars studied are resistant to GRV and its satellite but not to GRAV (Murant *et al.*, 1989, Bock *et al.*, 1990). Efforts are under way to produce rosette-resistant early-maturing cultivars.

VI. Tomato spotted wilt tospovirus (TSWV)

The groundnut disease caused by TSWV is referred to as 'bud necrosis'. TSWV is widely distributed and causes serious losses in yield in India, Nepal, China, USA and Australia. Early infection often leads to total crop loss.

TSWV produces a wide range of symptoms in groundnut. This has complicated diagnosis and led to the disease being given several different names (Reddy, 1988). Since TSWV particles are extremely unstable, special techniques are required to achieve mechanical transmission as well as for the purification of the particles.

1. Symptoms

Although bud necrosis and characteristic ring spotting of leaflets are commonly produced by TSWV, they are not diagnostic. Symptoms first appear in young leaflets as chlorotic spots or mottling that may develop into chlorotic and necrotic rings and streaks. When temperatures are relatively high, petioles bearing fully expanded leaflets with initial symptoms usually become flaccid and droop; this is soon followed by necrosis of the terminal bud. If the plant is young, it may become totally necrotic.

Secondary symptoms of the disease include stunting and proliferation of axillary shoots. Leaflets formed on axillary shoots show a wide range of symptoms including reduction in size, distortion of the

lamina, mosaic mottling and general chlorosis. These secondary symptoms are commonest in plants infected early and may have been attributed to rosette disease in earlier reports of the occurrence of rosette disease in India (Reddy, 1988).

Seed from plants infected early are small and shrivelled, and their testas show red, brown or purple mottling. Late-infected plants may produce seed of normal size, but the testas of some seeds are likely to be mottled.

2. Diagnosis

TSWV resembles animal viruses belonging to the family Bunyaviridae. In thin sections, the virus particles can be seen to occur often in membranous vesicles.

Several methods can be used to detect TSWV, the most rapid being ELISA or electron microscopy. TSWV can infect more than 250 species of plants (Reddy & Wightman, 1988), and the reaction of some is diagnostic for TSWV. TSWV induces concentric necrotic or chlorotic lesions in *Vigna unguiculata* (cowpea; several cultivars), and necrotic lesions in *Petunia hybrida*.

It is clear that there are several serologically distinct tospoviruses. TSWV isolated from groundnut in India failed to react with TSWV antisera prepared against Georgian and Texan isolates of TSWV, and antisera prepared against a TSWV isolate in India failed to react with a TSWV isolate from Georgia. Thus it is essential to test antisera from different sources for the identification of TSWV.

TSWV has an extremely low thermal inactivation point (45°C for 10 min) and short longevity *in vitro* (less than 5 h at room temperature). These characteristics can be used in conjunction with other methods to identify TSWV.

3. Transmission

TSWV is mechanically transmissible. The virus is extremely unstable, and antioxidants such as mercaptoethanol (0.2%) or thioglycerol (0.2%) must be added to the buffer (e.g. 0.05 M phosphate, pH 7.0) used to extract leaves for the preparation of inoculum. Extracts should be kept cold during preparation and inoculation, and only young leaves showing early symptoms should be used for preparing inocula.

TSWV is transmitted by thrips. *Frankliniella schultzei* was shown to be the principal vector in the Indian subcontinent (Amin *et al.*, 1981). Very recently *Thrips palmi* was found to be present in several locations (Palmer *et al.*, in press) and its role as a vector is currently being studied. In the southern USA, *F. occidentalis* and *F. fusca* are considered likely to be the primary vectors of TSWV. However, the principal thrips vectors in other regions where TSWV is economically important in groundnut have not yet been identified.

TSWV is not seed-transmitted in groundnut.

4. Control

Both TSWV and its vector thrips have wide host ranges among crop plants, ornamentals and weeds. Vector thrips are carried by wind. Some vector thrips such as *F. fusca* infest groundnut and can contribute to secondary spread within groundnut crops.

As TSWV is not seed-transmitted, seed from TSWV-infected plants is not a virus source.

Several cultural practices reduce TSWV incidence. Sowing crops well before thrips are expected to invade prevents the development of severe disease. For instance, at the ICRISAT Center in peninsular India, groundnut crops sown at the onset of monsoon rains in mid- to late-June have a much lower incidence of TSWV than later-sown crops.

Groundnut crops produce the best yields when they are sown to give the correct population density, i.e. one that gives a complete canopy quickly. By using good quality seeds, and seed treatment and irrigation where appropriate, it is possible to maintain optimal plant density, and the incidence of TSWV under these conditions is much reduced.

It is not practical to destroy weed reservoir hosts on small tropical farms. Fortunately many groundnut genotypes that have been identified at ICRISAT consistently produce crops with a lower incidence of TSWV than other susceptible cultivars. Several high-yielding cultivars with this field resistance to TSWV are currently available.

VII. Peanut stunt cucumovirus (PSV)

PSV is widely distributed in the south-eastern USA, East and South-east Asia, Europe and Africa, and occurs mainly in beans and forage legumes (Tolin, 1984; Ahmed & Mills, 1985; Zeyong *et al.*, 1986; Kim *et al.*, 1988; Zeyong & Zongyi, 1988). It can cause crop losses of up to 75%. Though PSV caused economically important epidemics in the USA in the mid-1960s, it is now only a minor disease in that country.

1. Symptoms

In the USA, PSV causes severe dwarfing of either the entire plant or of one or more branches depending on the age when the plant is infected (Tolin, 1984). In China, PSV does not cause severe stunting (Zeyong & Zongyi, 1988); petioles are shortened, and leaflets are reduced, malformed and chlorotic. Very few pods are produced on early-infected plants and they are misshapen and frequently have a split pericarp wall. Viability of seed from such pods is markedly reduced.

2. Diagnosis

Two serologically distinct isolates, PSV-E (from the eastern USA) and PSV-W (from the western USA) have been recorded (Tolin, 1984). Zeyong *et al.*, (1986) reported three additional serotypes PSV-T, PSV-2, and PSV-B2.

When inoculated with PSV, *Chenopodium amaranticolor* and *C. quinoa* produce local chlorotic and necrotic lesions, whereas *Vigna unguiculata* (cv. Blackeye) produces epinasty with systemic mosaic and malformation (Mink, 1972; Zeyong *et al.*, 1986).

3. Transmission

PSV is readily transmitted by sap inoculation. Three species of aphids, *Aphis craccivora, A. spiraecola* and *Myzus persicae* transmit the virus in the non-persistent manner.

PSV is seed-transmitted but with a low frequency. Large seeds, especially from late-infected plants, yield only 0.01% or fewer infected plants, whereas small seeds, selected from relatively less severely stunted plants, may yield up to 0.20% infected plants (Troutman *et al.*, 1967; Kuhn, 1969).

4. Control

In the USA, forage legumes such as white clover were shown to be the primary source of PSV; the incidence of the virus was negatively correlated with the distance of a groundnut crop from white clover. Roguing of infected plants from seed-production crops is recommended. No groundnut genotypes resistant to PSV are available (Tolin, 1984).

VIII. Cowpea mild mottle carlavirus (CMMV)

Groundnuts naturally infected with CMMV have been found in several countries in Asia and Africa. Incidence was usually low but could reach 30% when groundnuts were grown adjacent to very susceptible crops such as cowpea and soyabean (Iizuka *et al.*, 1984; Reddy & Rajeshwari, 1984).

1. Symptoms

Young quadrifoliate leaves show vein clearing and then roll downward. Leaflets and petioles develop necrosis. Plants are severely stunted and are conspicuous in the field because of the rolling of leaf edges, the necrosis on older leaflets, and the vein-banding symptom on younger leaflets.

2. Diagnosis

CMMV induces necrotic local lesions in *Beta vulgaris* and *Chenopodium amaranticolor.*

Antisera to CMMV are available from several sources, and CMMV also reacts with antisera to groundnut crinkle virus.

The CMMV genome is a single molecule of single-stranded RNA with *M*r of 2.6×10^6.

3. Transmission

CMMV is readily transmitted by mechanical inoculation of sap. It is also transmitted by the whitefly *Bemisia tabaci* in a non-persistent manner (Muniyappa & Reddy, 1983). Although CMMV is seed transmitted in cowpea and soyabean, seed transmission has not been reported in groundnut.

4. Control

Cowpea, soyabean and other hosts which are hosts of *B. tabaci* and are susceptible to CMMV are likely to provide sources of inoculum to groundnut. Thus, sowing of groundnuts near cowpea and soyabean fields, or intercropping groundnut with hosts which are highly susceptible to CMMV should be avoided, especially in seasons when the whitefly population is likely to be high.

No information is available on sources of resistance in *A. hypogaea.*

IX. Cucumber mosaic cucumovirus (CMV)

CMV is currently recognized as economically important in northern parts of China (Zeyong & Barnett, 1984; Zeyong *et al.*, 1989). It can cause crop losses of up to 40%.

1. Symptoms

Initial symptoms appear as chlorotic spots which later become yellow. Adjacent spots coalesce forming large yellow blotches. Some of the older leaflets also show green stripes along the veins. Plants are stunted.

2. Diagnosis

CMV has a wide host range. The isolate from China could be distinguished from other CMV isolates by symptomless infection of *Cucumis sativus* and *Lycopersicon esculentum*.

Antisera to CMV are available from several sources. CMV from China reacted with antisera to CMV-D and CMV-CI but not with CMV-S. It also reacted weakly with PSV occurring in China.

CMV particles contain three species of single-stranded RNA with *Mr* of 1.16×10^6, 1.05×10^6 and 0.81×10^6 and a sub-genomic RNA with *Mr* 0.39×10^6.

3. Transmission

CMV is transmitted by mechanical sap inoculations and by the aphid *Macrosiphum euphorbiae* in the non-persistent manner. It is seed-transmitted up to 2% in groundnut.

4. Control

Seed was shown to provide the primary source of inoculum in China. Planting with virus-free seed reduced disease incidence and delayed occurrence by over a month. Mulching with transparent plastic sheet also reduced CMV incidence in China. No information is available on sources of resistance in *A. hypogaea*.

X. Witches' broom

Though it is not a virus disease but is caused by mycoplasma-like organisms (MLOs), it is included here because it is widely distributed in South and Southeast Asia and witches' broom diseases were thought to be caused by viruses before the MLOs were identified.

The main symptom of witches' broom is axillary shoot proliferation which results in bushy plants. Leaflets are pale yellow and reduced in size, but not otherwise deformed. Pegs tend to grow upwards and pod yields are greatly reduced.

The MLO is transmitted by leafhoppers. *Orosius* species appear to be the principal vectors, but the different species of *Orosius* present in different countries have not been investigated.

An antiserum has been produced (Hobbs *et al.*, 1987) which can detect the MLOs by ELISA, but it is not known how specific it is nor whether many serologically distinct MLOs cause witches' broom in different parts of the world.

Several hundred groundnut genotypes have been screened for their resistance to witches' broom in Taiwan in Peneng Islands where the incidence of the disease commonly exceeds 80%, and several genotypes which performed consistently well have been identified. They will be utilized to develop resistant cultivars.

XI. Conclusions

I suggest that there are several immediate goals for research on groundnut viruses. 1) The development of probes that can detect several serological variants of PCV is important. These probes are indispensable for disease surveys and for identifying genotypes resistant to this important disease. 2) Information is needed on the epidemiology of such economically important viruses as PStV, TSWV and viruses involved in the etiology of groundnut rosette disease. 3) Identification of the principal thrips vectors of TSWV is required, especially in Asia. 4) The development of groundnut cultivars resistant to PCV is important. This may involve the use of non-conventional methods, such as introduction of viral genes into plants by biotechnological techniques. 5) Training in detection methods and the provision of necessary diagnostic aids for research workers in developing countries should be improved. This should greatly aid the implementation of the strict quarantine regulations for the import and export of seed necessary to prevent spread of viruses such as PMV and PStV, which occur frequently in groundnut germplasm in countries where they are endemic.

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Table 1. Features for identification of major groundnut virus diseases (particle morphology and serological reactions).

Virus and virus group	Particle morphology	Serological reactions	
		Viruses related	Viruses unrelated
Peanut mottle potyvirus	Flexuous rods 740–750 nm length 13 nm width	Azuki bean mosaic	Bean yellow mosaic Groundnut eyespot Peanut green mosaic Peanut stripe
Peanut stripe potyvirus	Flexuous rods 752 nm length 13 nm width	Blackeye cowpea mosaic Clover yellow vein Soybean mosaic	Bean yellow mosaic Peanut mottle
Peanut clump furovirus	Two rod shaped particles 245 nm length 160 nm length 24 nm width	Exists as several serologically distinct variants. Cross reaction occurs among some variants	Beet necrotic yellow vein Potato mop top Soil-borne wheat mosaic
Groundnut rosette assistor luteovirus	Luteovirus 28 nm	Barley yellow dwarf Bean leaf roll Beet western yellows Potato leaf roll	Carrot red leaf Subterranean clover red leaf Tobacco necrotic dwarf
Groundnut rosette virus and its satellite RNA	Particles specific for rosette virus RNA and its satellite not detected so far	–[a]	–[a]
Tomato spotted wilt tospovirus (Indian isolates)	Circular with a double membrane of protein and lipid, 70–90 nm diameter	Homologous only	Tomato spotted wilt virus isolates from USA, Netherlands, Australia, Japan
Tomato spotted wilt tospovirus (USA isolates)	Circular with a double membrane of protein and lipid, 70–90 nm diameter	Tomato spotted wilt virus isolates from USA, Netherlands, Australia	Tomato spotted wilt virus isolates from India
Peanut stunt cucumovirus	Spherical 25–30 nm diameter	Several peanut stunt virus isolates from USA	–[b]
Cowpea mild mottle carlavirus	Slightly flexuous rods 610 nm length 15 nm width	Cowpea mild mottle virus; isolates from different countries cross react Groundnut crinkle virus	–[b]
Cucumber mosaic cucumovirus	Spherical 28 nm diameter	Several isolates of cucumber mosaic and peanut stunt	–[b]

[a]Not applicable.
[b]Data not given because of their limited value for identification.

Table 2. Features for identification of major groundnut virus diseases (transmission, biological properties and diagnostic hosts).

Virus	Transmission			Biological properties		Diagnostic hosts	
	Mechanical sap	Biological agents	Seed of groundnut	TIP[a] °C	LIV[b] at 4°C h = hours d = days	Local lesions	Systemic
Peanut mottle	+	Aphids	+	55–65[c]	up to 7 d[c]	*Phaseolus vulgaris* (Topcrop)	*Glycine max* *Pisum sativum*
Peanut stripe	+	Aphids	+	55–60[c]	3 d	*Chenopodium amaranticolor* *C. quinoa*	*Glycine max* *Lupinus albus* *Vigna unguiculata*
Peanut clump i) Indian isolates	+	*Polymyxa graminis* (fungus)	+	60–65	20 d	*Chenopodium quinoa* *C. murale* *Vigna unguiculata*	*Canavalia ensiformis* *Nicotiana clevelandii* *N. edwardsonii* *N. glutinosa*
ii) West African isolates	+	*Polymyxa graminis* (fungus)	+	65	28 d	*Chenopodium amaranticolor* *Vigna unguiculata*	*N. glutinosa*
Groundnut rosette assistor	–	Aphids	–	–	–	–	*Capsella bursa-pastoris*
Groundnut rosette and its satellite RNA	+	+[d]	–	NA[e]	NA[e]	*Chenopodium amaranticolor*	*Nicotiana benthamiana* *N. clevelandii*
Tomato spotted wilt	+	Thrips	–	45	5 h	*Chenopodium amaranticolor* *C. quinoa* *Petunia hybrida* *Vigna unguiculata*	*Lycopersicon esculentum* *Nicotiana glutinosa* *N. tabacum*
Peanut stunt	+	Aphids	+	55–60	4 d	*Chenopodium amaranticolor* *Vigna unguiculata*	*Datura stramonium* *Glycine max* *Nicotiana tabacum*
Cowpea mild mottle	+	*Bemisia tabaci* (whitefly)	–	75–80	8 d	*Beta vulgaris* *Chenopodium quinoa* *Cyamopsis tetragonoloba*	*Glycine max* *Phaseolus vulgaris*
Cucumber mosaic	+	Aphids	+	55–60	7 d	*Chenopodium amaranticolor* *Datura stramonium* *Vigna mungo*	*Nicotiana tabacum* *Vigna unguiculata*

[a]Thermal inactivation point.
[b]Longevity *in vitro*.
[c]Strain-dependent.
[d]Aphid-transmitted only when the source plant is co-infected with groundnut rosette assistor luteovirus.
[e]Not available.

Table 3. Symptoms and distribution of minor groundnut virus diseases.

Virus	Symptoms on groundnut	Geographical distribution	Reference
Groundnut streak necrosis	Initial symptoms are discrete, bright yellow spots 1–2 mm diameter. Subsequently produced leaflets show a range of symptoms which include yellow spots or ringspots and line patterns. The most conspicuous symptoms are necrotic streaks along the veins; leaflets are reduced in size, distorted and puckered. Late-infected plants may show yellow streaky patches or flecks, often in irregular lines, and restricted to margins of leaflets.	Kenya, Tanzania, Malawi and Zambia	Bock, 1989
Peanut yellow spot tospovirus	Yellow spots which later coalesce, and become necrotic. Not systemic.	India, Thailand	Reddy *et al.*, 1991 Wongkaew & Sae-Wein, 1984
Peanut green mosaic potyvirus	Vein clearing, severe mosaic with green islands. Isolates which produce different symptoms have been identified.	India	Sreenivasulu *et al.*, 1981
Groundnut eyespot potyvirus	Leaflets show yellow eye-spots with a dark green ring; a dark green vein banding may appear along the veins. Plants are not stunted.	Côte d'Ivoire, Burkina Faso and Mali	Dubern & Dollet, 1980
Groundnut crinkle carlavirus	Slight mottle and crinkling of leaflets.	Côte d'Ivoire	Dubern & Dollet, 1979
Bean yellow mosaic potyvirus	Initial symptoms are characteristic chlorotic spots and rings which fade as plants mature.	USA	Bays & Demski, 1986

Table 4. Features for identification of minor groundnut virus diseases.

Virus[a]	Diagnostic hosts: Local lesions	Diagnostic hosts: Systemic	Particle morphology	Serological relationships
Groundnut streak necrosis	*Chenopodium amaranticolor*	*Nicotiana benthamiana* *Tridax procumbens* *Helianthus annus*	No particles detected[b]	–[c]
Peanut green mosaic	*Chenopodium amaranticolor* *C. quinoa* *Phaseolus vulgaris* (Local)	*Petunia hybrida* *N. clevelandii*	Flexuous rods (potyvirus)	Related to peanut stripe, soyabean mosaic and blackeye cowpea mosaic viruses but not to peanut mottle virus.
Peanut yellow spot	*Vigna unguiculata*	*Vigna mungo*	70–90 nm surrounded by a double membrane (tospovirus)	Serologically distinct from tomato spotted wilt virus
Groundnut eyespot	*V. unguiculata* *Pisum sativum*	*P. hybrida* *Canavalia ensiformis*	Flexuous rods (potyvirus)	Related to guinea grass mosaic, passion fruit ringspot; soyabean mosaic; not related to blackeye cowpea mosaic, clover yellow vein, bean common mosaic and bean yellow mosaic viruses.
Groundnut crinkle	*Glycine max* *V. unguiculata*	*Centrosema pubescens*	Slightly flexuous rods (carlavirus)	Related to cowpea mild mottle virus
Bean yellow mosaic virus	*C. amaranticolor* *Phaseolus vulgaris* (Bountiful)	*Phaseolus limensii* *Trifolium incarnatum*	Flexuous rods (potyvirus)	Clover yellow vein

[a]None of these viruses are known to be seed-transmitted.
[b]A similar situation to that described in groundnut rosette is predicted from research currently being conducted by Dr A.F. Murant at the Scottish Crop Research Institute, UK. No virus-like particles have been found in infected plants but there is abundant infective SS RNA.
[c]Information not available.