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Diseases of Groundnut

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Abstract

A large number of diseases are known to be associated with groundnut crop, however, only some of them cause economic losses. This article describes in detail the major diseases of groundnut, its occurrence, distribution, losses caused by them, diagnostic symptoms and their epidemiology (spread survival and transmission) besides aflatoxin contamination of groundnut. The various management options and the status of research are reviewed. It covers the disease management approaches like host plant resistance, cultural methods, use of botanicals, biological control, chemical methods and biotechnological approaches. The integrated disease management approach is discussed for major diseases including management of aflatoxins. The current research needs is also discussed.

Key words: Groundnut, diseases, rust, leaf spots, stem rot, aflatoxins, integrated disease management

Groundnut (*Arachis hypogaea*) is an important oilseed crop in India and is cultivated during *kharif* and *rabi*-summer. Gujarat, Andhra

Pradesh, Tamil Nadu, Karnataka, Rajasthan and Maharashtra are major groundnut growing states contributing about 80 percent area and production in India. The average yield of *rabi*-summer groundnut is around 1600 kg/ha, whereas *kharif*-groundnut is around 1000 kg/ha which is lower than major groundnut growing countries. This may be attributed to the rainfed nature of cultivation of this crop coupled with attack by a variety of diseases and insect pests. The role of groundnut diseases in reducing yield has been clearly demonstrated (Ghuge *et al.*, 1981; Ghewande *et al.*, 1983; Subramaniyam *et al.*, 1985). More than 55 pathogens including viruses have been reported to affect groundnut.

Among diseases, stem rot, collar rot, aflaroot, leaf spots (early and late), rust and bud necrosis affects the groundnut crop both in *kharif* and *rabi*-summer. However, the incidence and severity of these diseases may vary from season to season. Diseases reduce the pod yield of groundnut and also fodder quality of haulm. Of the seed and seedling diseases, collar rot/seedling blight (*Aspergillus niger* van Tieghem), stem rot/Sclerotium wilt (*Sclerotium rolfsii* Sacc) dry wilt or dry root rot (*Macrophomina phaseolina* (Tassi) Goid = *Rhizoctonia bataticola* (Taub., Butler) have been recognized as economically important diseases. These diseases cause severe seedling mortality resulting in patchy crop stand mostly in sandy loam soil and reduce the yields from 25-50% (Chohan, 1974; Ghewande, 1985). Among the foliar fungal diseases, economically important are early leaf spot, late leaf spot and rust. Early leaf spot is caused by *Cercospora arachidicola* Hori (Perfect stage-*Mycosphaerella arachidis* Deigton) and late leaf spot is caused by *Phaeoisariopsis personata* Berke & Curt (Perfect stage-*Mycosphaerella berkeleyi* Jenkins) both commonly called '*tikka* disease'. These diseases occur wherever the groundnut crop is grown. However, the incidence and severity of each disease varies between localities and seasons and there can be both short and long term fluctuations in their relative proportions (Mc Donald *et al.*, 1985). The magnitude of yield losses caused by these diseases is very high and ranged from 10 to 70% all over the world, but vary considerably from place to place and between seasons (Ghewande, 1983; 1985; 1990a; Subrahmaniyam and Mc Donald, 1983). Among viral diseases, groundnut bud necrosis, peanut mottle, Indian peanut clump and stem necrosis diseases are economically important. Groundnut bud necrosis disease caused by *Groundnut bud necrosis tospovirus* is widespread with a wide host range and is transmitted by *Thrips palmi* (Kendre *et al.*, 2000). The incidence of the disease was

observed to be as high as 92% on Spanish bunch varieties of groundnut during 1985 (Summer) in Jamnagar district of Saurashtra region of Gujarat (Ghewande, 1987). It has been reported to cause yield loss of up to 50% in early infected crop of groundnut in India (Ghanekar, 1980). Besides these, in the past three years, *Alternaria* leaf blight had been occurring severely in summer groundnut (Kumar *et al*., 2012). More than 70 species of plant parasitic nematodes have been reported in association with groundnut disease (Sharma and Mc Donald, 1990) but only a few species are known to cause economically important disease (Subrahmaniyam *et al*., 1990). Pod and root knot disease caused by four species of *Meloidogyne viz. M. arenaria* (Neal) Chitwood, *M. hapla* Chitwood, *M. incognita* Kofoid & White and *M. javanica* (Treub) Chitwood is the most important disease of groundnut. *M. arenaria* is the most widespread. The nematode (*Tylenchorynchus brevilineatus*) induced disease locally known as "Kalahasti malady" was observed in Chittoor and Nellore district of Andhra Pradesh is also locally important. Besides these, aflatoxin contamination in groundnut and its processed product is another major challenge to groundnut growers, processors and exporters.

The major diseases of groundnut can be managed through a variety of methods like use of resistant/tolerant cultivars, cultural practices, biocontrol agents/bio-pesticides, and need based application of fungicides. In the following paragraph, major diseases of groundnut and its management practices are discussed.

Major diseases of groundnut

Seed and seedling diseases

1. Collar rot (*Aspergillus niger*)

It is prevalent in almost all groundnut-growing states and the losses in terms of mortality of plants ranges from 28 to 50%. It is particularly serious in the sandy loam and medium black soil of the Punjab, Tamil Nadu, Uttar Pradesh, Rajasthan and Haryana.

The fungus present in the soil or adherent on seed surface germinates and attacks the seeds before its germination and causes pre-emergence rotting of seeds. It also causes rotting of hypocotyls, post-emergence seedling blight, rapid wilting of entire plant or its branches which are characteristic diagnostic symptoms. Collar region of the affected plants

becomes shredded and becomes dark brown covered by mycelia growth and spores.

Soil borne inoculum is the primary source of infection. The pathogen can tolerate low soil moisture (13-16 %). The fungus develops best at temperature between 31 and 35°C.

2. Stem rot (*Sclerotium rolfsii*)

In India, stem rot occurs in all groundnut growing states, particularly more severe in Gujarat, Maharashtra, Madhya Pradesh, Odisha and Tamil Nadu, where approximately over 50,000 ha of groundnut fields are infected with *S. rolfsii*. Latur, Raichur, Dharwad, Junagadh and Hanumangarh have been identified as 'hot spots' for the diseases. About 27% or more yield loss due to this disease has been reported from India (Chohan, 1974). Mayee and Datar (1988) have reported yield losses of over 25% in Maharashtra. The indirect losses such as reduction in dry weight and oil content are also reported.

The initial symptoms are partial or complete wilting of the stem or branches that are in contact with the infected soil. White mycelia growths with brown colour sclerotia are visible on the infected plant parts. The leaves turn brown and show wilting but remain attached to the plant. Infection of pegs, pod rot and leaf blight are another symptoms of stem rot infected plants.

The pathogen has a wide host range. *S. rolfsii* can colonize either living plant tissues or plant debris. Deeply buried sclerotia survive a year or less while those near soil surface remain viable for many years. Defoliated leaves can also serve as a bridge to facilitate plant to plant spread. The pathogen spreads through infected soil, wind splashed rain and sclerotia. Types of crop residue particularly influence the sclerotial germination, mycelia growth and infection by *S. rolfsii* in groundnut (Kumar *et al.*, 2010; 2011). Soil moisture to the extent of 40 to 50% of water holding capacity and temperature between 29 to 32°C during day and 25°C during nights favours the pathogen infection and disease development.

3. Dry root rot (*Macrophomina phaseolina)*

Also known as dry wilt or charcoal rot is sporadic in occurrence and is particularly serious in Rajasthan, Uttar Pradesh, Tamil Nadu, Andhra Pradesh and Maharashtra. The pathogen causes severe seedling mortality resulting in patchy crop stand and thus reduces

the yield.

The symptoms appear as water soaked necrotic lesion that girdles the stem just above the ground level and wilting follows. The tap root turns black and later rots and shreds. Kernels turn black with abundant sclerotia on inner wall of the shell and surface of the testa.

The pathogen has wide host range. The pathogen is a facultative saprophyte and a soil dweller. Infected soil, plant debris and pods serve as sources of inoculums. The optimum temperature for seedling infection is 29 to 35°C and for pods invasion is between 26 and 32°C. The sclerotia are disseminated via plant debris, soil, infected pods, shell, and kernel.

4. Aflaroot/yellow mold (*Aspergillus flavus*)

It is prevalent in almost all groundnut-growing states. The yellow mold fungus, *A. flavus* is commonly found in the seed of both rotten and apparently healthy pods of groundnut. It first appears on cotyledons after the emergence of seedlings. Infected plants generally become stunted and leaf lamina is drastically reduced with a pointed tip. Vein clearing and chlorosis of the leaflets is also visible. Infected seedlings lack a secondary root system, a condition known as "aflaroot." Such plants do not produce flowers and hence become unproductive. Yellow-green *Aspergillus* colonies develop on over mature and damaged seeds and pods.

Soil borne inoculum is the primary source of infection. The pathogen can tolerate low soil moisture and the fungus develops best at temperature between 25 and 35°C.

Foliar fungal diseases

1. Early leaf spot (*Cercospora arachidicola*)

Early leaf spot disease had been more prevalent in northern groundnut growing states however in the last decade it has assumed a serious status in southern and central groundnut growing states too. The losses in yield estimated to be in the range of 15 to 59%. Besides the losses in pod and kernel yield, the fodder quality is also adversely affected.

The disease normally occurs 30 days after sowing. Initially minute circular to sub-circular chlorotic spots, 1 to over 10 mm in diameter

develop on upper surface of leaf which later turn to brown in colour and surrounded by yellow halo. Most sporulation occurs on the upper surface of leaflet. Severely infected leaves may drop off prematurely. The lesion may extend to the stem and branches.

The pathogen survives through conidia on affected plant debris in soil or through conidia being carried on the pod shell. The pathogen also survives from one season to another on volunteer groundnut plants. Temperature between 25 and 30°C, prolonged leaf wetness hours, and high RH (>80%) favours the infection and disease development. Conidia disseminated by wind causes secondary infection.

2. Late leaf spot (*Phaeoisariopsis personata*)

Commonly occurs wherever groundnut is grown and yield losses ranges from 15 to 59%, but vary from place to place and between seasons. Besides the losses in pod and kernel yield, the fodder quality is also adversely affected.

The disease normally occurs on 60 days old crop to till harvesting. Dark brown to black, circular to sub-circular lesions measuring 1-6 mm diameter appear on lower surface of the leaves where most sporulation occurs. Several lesions may coalesce and in severe cases, infected leaves may drop off prematurely. Oblong lesions occur on the stem and branches.

As of early leaf spot pathogen, the late leaf spot pathogen survives through conidia on affected plant debris in soil or on the infected groundnut shell and also from one season to another on volunteer groundnut plants. Temperature between 25 and 30°C, prolonged leaf wetness hours, and high RH (>80%) favours the disease. Long distance distribution of the pathogens may be by airborne conidia, by movement of the infected crops debris or by movement of pods or seeds that are surface contaminated with conidia. Early and late leaf spot pathogens are also soil borne (Mc Donald *et al.,* 1985). Differences in the characteristics of early and late leaf spots are as under:

3. Rust (*Puccinia arachidis*)

The disease is prevalent throughout groundnut growing areas but more severe in the southern states. Losses in yield due to rust have been reported in the range of 10 to 52%. In addition to yield loss, the disease reduces seed size and oil content of groundnut.

Difference between early and late leaf spots

S. No.	Characteristics	Early leaf spot	Late leaf spot
1.	Seasonal development	Early	Late
2.	Shape of spot	Circular to irregular	Usually circular
3.	Leaf surface where first and most spores produced	Upper	Lower
4.	Colour of spot on upper leaf surface	Light brown to black tending towards brown	Brown to black tending towards black
5.	Colour of spot on lower leaf surface	Brown	Black

Initially chlorotic spots develop on the upper surface of the leaf. Corresponding lower surface shows orange colored pustules (uredinia). The pustules range from 0.5 to 1.4 mm in diameter. Severely infected leaves turn necrotic and desiccate but remain attached to the plant. The kernels formed in the affected plants are shriveled and small.

The disease perpetuate through urediniospores. In India, groundnut crop or volunteer plants are available in one or the other parts of the country enabling the survival of uredinial stage round the year. The pathogen may also survive from season to season on self sown (volunteer) groundnut plants.

An optimum temperature of 20°C, prolonged leaf wetness hours, and high humidity favours the rust disease. Spread of the disease within growing crops is facilitated by wind movement, by rain splash, and also by insects (Subrahmaniyam and Mc Donald, 1987).

4. Alternaria Leaf Blight (*Alternaria* spp.)

The leaf blight disease of groundnut is caused by *Alternaria alternata* (Fr.) Keissler, as reported by Balasubramanian (1979), Subrahmanyam *et al.* (1981), Vyas *et al.* (1985) and Narain *et al.* (1987) and also were caused by *Alternaria tenuissima* (Kunze. Fr) Wiltshire as reported by Patil and Hiremath (1989) and Ghewande *et al.* (1982). Two other species of *Alternaria* reported from groundnut are *Alternaria arachidis* Kulk. described by Kulkarni (1974) cause the brown leaf spot symptom, and *Alternaria longipes* described by Giri and Murugesan (1996) cause necrotic leaf spots. The leaf blight caused by *A. alternata* has been

hitherto a minor disease of groundnut. However, in summer crop of 2009 a widespread occurrence of this disease was observed in severe form in farmers' fields in Junagadh, Rajkot and Kuchchh districts of Gujarat (Kumar *et al.*, 2009). Since then this disease had been occurring in severe form on summer groundnut. The disease reduced pod (upto 22%) and fodder (up to 63%) yield depending on severity.

The characteristic symptoms of the disease are blighting of the apical portions of leaflets, which turn light to dark brown in colour. In the later stages of infection, blighted leaves curl inward and become brittle. Adjacent lesions coalesce giving the leaf a ragged and blighted appearance. Disease develops more rapidly on the upper portion of the canopy than on the lower portion.

Self sown (volunteer) groundnut plants as primary inoculums and secondary spread through conidia. It has several weed hosts including aquatic weeds like water hyacinth (*Eichhornia crassipes*) and pistia (*Pistia stratiotes*). Water hyacinth is commonly found in water reservoirs. The sources of the inoculums in epidemics of *Alternaria* leaf blight may come from sesame, sunflower or the weed hosts, besides the left over plants of previous season crops

A. alternata requires relative humidity of 85% and above (Reis *et al*., 2006) and optimum temperature range of 25-30°C for conidial production (the maximum conidia being formed at 20°C and only a few above 32°C) (Stavely and Main, 1970).

Virus diseases

1. Groundnut bud necrosis (*Groundnut bud necrosis tospovirus*)

The occurrence of bud necrosis disease on groundnut was first reported from India by Reddy *et al.* (1968). This is the most important virus diseases of groundnut, widely distributed and causes yield losses from 30 to 90% depending upon plant growth stage at the time of infection. The hot spot locations are Jagtiyal and Hyderabad in Andhra Pradesh, Latur in Maharastra, Tikamgarh in Madhya Pradesh, Raichur in Karnataka and Mainpuri in Uttar Pradesh.

The typical symptoms of the disease include terminal bud necrosis, severe stunting and proliferation of axillary shoots. Necrosis of the bud may spread to the petiole and stem, sometimes leading to death of the plants. In late infections pod size is reduced. Seeds are often

shrivelled and have mottled and discoloured testa (Reddy *et al.*, 1991).

Groundnut bud necrosis virus is also known as *Peanut bud necrosis virus* (PBNV). It is placed in the genus *Tospovirus* belongs to the family *Bunyaviridae*. The virion is quasi-spherical in shape, contain a segmented genome of three single-stranded RNA molecules that are each bounded by a nucleocapsid protein to form ribonucleoproteins which are encased within a lipid envelope consisting of two virus coded glycoproteins and a host-derived membrane. Large (L), medium (M), and small (S) RNA segment were characterized based on nucleotide sequence, genome organization and homology to other tospoviruses (Satyanarayana *et al.,* 1996a, 1996b; Akram *et al.,* 2004; Venkatesan *et al.,* 2009; Lokesh *et al.,* 2010).

Thrips palmi was identified as efficient vector of PBNV which transmits in circulative and propagative manner. The 1st or 2nd stage larva acquires the virus and transmits during adult stage. The vector is viruliferous throughout its life time nevertheless, transovarial transmission is absent.

The pathogen has a wide host range and survives on ornamentals (*Zinnia*, cosmos and sunflower), weeds (*Ageratum conyzoides*, *Cassia tora*, *Acanthospermum hispidum*, *Desmodium triflorum*) and crop plants (tomato, brinjal, green gram, black gram, beans and pea).

Temperature 30°C and a wind speed of 10 km/h favour migration of thrips. The thrips population increases rapidly in late August and September. The population builds up again during January and February and hence *rabi* season crop also suffers very seriously.

2. Groundnut Stem Necrosis (*Tobacco streak ilarvirus*)

The disease is distributed in Anantapur district and to some extent in the adjoining Cuddapah, Kurnool and Chittoor districts of Andhra Pradesh, and Raichur area of Karnataka. Surveys carried out in Gujarat and Maharashtra did not show the presence of the disease in surveyed areas (Porbandar, Rajkot, and Junagadh in Gujarat and Jalgaon in Maharashtra). The disease is caused by *Tobacco streak virus* (TSV) of the genus *Ilarvirus,* of the family *Bromoviridae* (Reddy *et al.,* 2002; Prasad Rao *et al.,* 2003a).

The characteristic symptoms of the disease are appearance of large necrotic lesions on young leaflets which later coalesce to cover entire

leaflet, followed by necrosis of entire stem located below the necrosed leaflet, leading to death of the plant.

TSV is pollen borne and probably is not transmitted through seed. Thrips vectors (*Frankliniella schultzei, Scirtothrips dorsalis* and *Megalurothrips usitatus*) aid in passive transmission of the virus, as carriers of pollen from infected plants. There was no evidence of ingestion of the virus by the vector (Shukla *et al.,* 2005). When the thrips infest groundnut plants, the pollen grains get dislodged from the insect's body and during the feeding process virus present in the pollen, infects the host plants. TSV infects a number of commonly occurring weeds and a few crop plants (Prasada Rao *et al.*, 2003a, b; Shukla *et al.,* 2005). It has been observed that *Parthenium hysterophorus* a widely distributed weed plays a major role in virus spread, mostly as symptomless carrier.

The distinguishing features of stem necrosis and bud necrosis disease (Modified from Prasad Rao *et al*., 2003a) are as under:

Disease	Groundnut stem necrosis	Groundnut bud necrosis
Causal Virus	*Groundnut stem necrosis virus*	*Groundnut bud necrosis virus*
Genus	Ilarvirus	Tospovirus
Symptoms	Necrotic lesions on terminal leaflets, complete stem necrosis and often total necrosis of entire plant.	Chlorotic lesions on terminal leaflets, ring spots and often necrosis of terminal bud.
	Axillary shoot roliferation, restricted to apical portion may occur.	Axillary shoot proliferation with small and deformed leaflets. Infected plants remain stunted and seldom die.
	Necrotic spots on pods. Testa is not discoloured or mottled.	No Necrotic spots on pods. Testa is discoloured and mottled.
	No evidence of seed transmission. Additional tests necessary.	Definitely not seed transmitted
Serological cross reaction	Ilarvirus in Bromoviridae Reacts with many tobacco streak virus antisera.	Distinct Tospovirus and reacts only with groundnut bud necrosis virus antiserum.
Seed transmission	Seed-transmitted in many hosts	Not seed-transmitted in any of the hosts
Transmission vectors	Transmission by *Frankliniella schultzei* in a persistent manner	Transmitted by several species of thrips. Relationship is passive.
Primary spread	Mostly weed hosts	Weed and crop plants

3. Peanut Mottle (*Peanut mottle potyvirus*)

Peanut mottle caused by peanut mottle (PMV) potyvirus is reported to occur mostly on *rabi*/summer groundnut mainly in the states of Andhra Pradesh, Maharashtra and Gujarat. The disease can cause up to 30% loss in yield (Kuhn and Demski, 1975). Newly formed leaves show mild mottling and vein clearing, whereas older leaves show upward curling and interveinal depression with dark green islands. Infected plants are not severely stunted and older plants seldom show typical disease symptoms. Some pods from plants infected with PMV may be smaller than normal and have irregular, green to brown patches. Seeds from such pods are discoloured. Yield losses of 15-45% have been recorded in India (Reddy *et al.*, 1978).

The virus is transmitted through the seed to the extent of 8.5% (Adams and Kuhn, 1977) and secondary transmission is by aphid species. The pathogen survives on several important legume crops (groundnut, soybean) and weeds (*Cassia obtusifolia, C. leptocarpa, C. occidentalis* and *Desmodium canum*). The primary source of inoculum is through seed and the secondary spread occurs through aphids. Prolonged dry spells favours the build-up of aphids population.

4. Peanut Clump (*Peanut clump furovirus*)

Indian peanut clump caused by peanut clump furovirus has been reported from Rajasthan, Punjab, Gujarat, Andhra Pradesh and Uttar Pradesh where, crops grown in sandy soils (Ghanekar, 1980). Symptoms are severe stunting, mosaic mottling and peeling of root epidermis. A yield loss up to 60% has been recorded in late infected plants.

The disease occurs in patches in the field. Young leaves show mosaic mottling and chlorotic ring symptoms. Older leaflets are darker green with faint mottling. Early infected plants are severely stunted and become dark green.

Indian peanut clump virus isolates are transmitted through seed (Nolt and Reddy, 1984). A soil-borne fungus (*Polymyxa graminis*) also transmits the virus (Ratna *et al*., 1991). *P graminis* has a wide host range and so the virus also perpetuates over seasons.

Nematode diseases

1. Root knot (*Meloidogyne arenaria, M. hapla* and *M. javanica*)

Nematode damage is frequently not suspected until roots and pods are examined. Plants infected by root knot nematodes commonly develop enlarged roots and peg which develop into galls of various sizes. Root development is commonly reduced. Severely infected plants are stunted and have chlorotic leaves.

2. Kalahasti malady (*Tylenchorhynchus brevelineatus*)

This is now a serious disease in Andhra Pradesh, particularly in Tirupati areas. Infected plants appear in patches in the field, and are stunted with greener than normal foliage. Small brownish yellow lesions appear on the pegs, and on young developing pods. Peg length is reduced. In advanced stages of the disease the entire pod surface becomes blackened and kernels become small.

Aflatoxins

Aflatoxin contamination due to invasion by *Aspergillus flavus* and *A. parasiticus* is a major problem in groundnut. Aflatoxins are potent toxic, carcinogenic, mutagenic, immunosuppressive agents, produced as secondary metabolites by the fungus. Among 18 different types of aflatoxins identified, major members are aflatoxin B_1, B_2, G_1 and G_2. Aflatoxin contamination although does not affect yield, but it causes serious health risks to human and cattle.

Groundnut pods when in direct contact with spores of *A. flavus* in soil are frequently invaded before harvest (Hill *et al.*, 1985; Horn *et al*., 1995). The mode and extent of invasion by *A. flavus* depends on soil population density of *A. flavus*, soil moisture and soil temperature during the pod development to maturity period. These fungi can invade and produce toxins in groundnut kernels before harvest, during drying and in storage. Kumar *et al*. (2008) conducted studies on prevalence and variability of soil population of *Aspergillus* spp. (specifically *A. flavus)* across major groundnut growing districts of Gujarat vis-à-vis aflatoxin contamination. Soil population of *A. flavus* was found low in summer crop (<4.0 x 10^3 *c.f.u.* /g soil) than in *kharif* (monsoon) crop (10-44 x 10^3 *c.f.u.* /g soil) in majority of the samples. The population increased towards pod development stage of the crop. Bhuj and Bhavnagar district had lowest population in both the crop seasons. In majority of the samples positive correlation was found with the population of *A. flavus* and level of aflatoxin contamination. Cropping system influenced the level of population. Various surveys conducted

in different parts of India have revealed that groundnuts and groundnut products are high-risk commodities for aflatoxin contamination. Kumar *et al.* (2008) reviewed the commodity-wise etiology and contamination process of the major mycotoxins and the magnitude of contamination in commercially important agricultural commodities.

Environmental conditions required to induce pre-harvest aflatoxin contamination of groundnuts was studied by Cole *et al.* (1989). They showed that groundnuts do not become contaminated with aflatoxins in the absence of severe and prolonged drought stress in spite of invasion levels of up to 80% by *A. flavus* and *A. parasiticus*. Also, larger, more mature groundnut kernels required considerably more drought stress to become contaminated than did smaller, more immature kernels. The role of environmental stress in predisposition of groundnuts to aflatoxin contamination was demonstrated by several workers (Sanders *et al.*, 1985; Thai *et al.*, 1990). Although, roots did not suffer drought stress, when pod suffered stress, risk of aflatoxin contamination increased (Sanders *et al.*, 1993). The rainy season crop is often subjected to drought, particularly end-of-season drought, in most of the areas in the major groundnut producing regions in India. This encourages *A. flavus* infection and aflatoxin contamination (Bhat and Rao, 1990; Ghewande, 1997). Since the development of genetic transformations systems for *A. flavus* and *A. parasiticus*, 10 genes have been isolated in the aflatoxin pathway and nine enzymatic conversions have been elucidated or confirmed (Payne and Brown, 1998; Bhatnagar *et al.*, 2003).

Management of major diseases

The changing production system scenario demands for cost effective, easily adaptable and eco-friendly tools for the effective management of the major diseases. Diseases management requires judicious adoption of the several management tools. The important among them are discussed below:

Cultural Practices

Several cultural practices like removal of volunteer plants, removal or burial of infected crop debris, crop rotation, organic amendments of soil, intercropping etc. are important for the management of diseases.

Removal of volunteer groundnut plants, removal or burial of infected crop debris, crop rotation and early sowing of the crop can reduce intensity of leaf spot and rust. Altering plant population could also reduce foliar disease severity (Ghewande *et al.,* 1983; Kodmelwar and Ingle, 1989). Intercropping groundnut with pigeon pea, cowpea, black gram, pearl millet, sorghum and other crops have been reported to reduce the intensity of foliar diseases. Deep ploughing of fields and rotation of groundnut with gram and wheat are useful in reducing the collar rot disease incidence (Sathiyanarayanmurthy *et al.*, 1988). Early sowing of groundnut in June reduces collar rot incidence. The crop planted with a spacing of 30 cm between the rows had lowest root rot incidence than when planted with a row spacing of 45 cm or 60 cm. Closer spacing reduced incidence of collar rot and stem rot in early sown crop. Cultural practices such as deep covering or burial of organic matter before planting, avoiding movement of soil up around the base of plant, prevention of development of organic debris are useful for reducing the incidence of stem rot. Cotton is a suitable rotation crop for management of *S. rolfsii* (Rodriguez and Morgan, 1987). Other rotation crops like maize, sorghum, onion and garlic are also useful for the management of stem rot. Plant density can be increased to decrease the proportion of infected plants of bud necrosis (Reddy *et al.*, 1983). Groundnut intercropped with pearl-millet and early sowing showed less incidence of bud necrosis disease as compared with sole crop at ICRISAT (Ghanekar, 1980). Cultivation of groundnut away from soybean, cowpea and navy beans could reduce peanut mottle virus considerably as in these crops the virus is seed transmitted and serve as foci of inoculums (Demski and Khun, 1983). Groundnut crop grown during *rabi* escapes the clump disease (Reddy, 1988). Soil borne pathogens can be effectively managed through deep ploughing during summer months, increased use of farmyard manure, deoiled cakes, other organic amendments and soil solarisation. Application of neem cake and farmyard manure to soil gave good control of collar rot (Karthikeyan, 1996). In pot experiment the best reduction of pre- and post- emergence death of seedlings infected by *S. rolfsii* was given by amendments of safflower oil cake and sun hemp which was more effective than seed dusting with captan (Kulkarni *et al.*, 1995). Rago *et al.* (1997) observed that there was no sclerotial production on lucerne residues. Wheat straw application reduced *Sclerotina* blight in 1992 and 1993 but not in 1994 compared with unamended plots (Ferguson and Shew, 2001). The crops like sesamum, castor and cotton are good

crops to include in rotations for reducing the incidence of *M. arenaria* (Rodriguez and Morgan, 1987; Rodriguez *et al.*, 1991). Poultry manure and neem cake amendments give good control of Kalahasti malady (*Tylenchorhynchus brevilineatus*) (Naidu *et al.*, 2000). Nematode problems in groundnut can be effectively managed through deep ploughing during summer months, increase use of F.Y.M. and other organic amendments and soil solarisation. For the management of foliar diseases especially leaf spots and rust, deep burying of crop residues, destruction of crop debris by burning, removal of affected groundnut plants, early planting and wider row spacing (40-45 cm) and intercropping of pearl millet, sorghum and pigeon pea have been advocated (Ghewande *et al.*, 2002). Early sown crops suffered least from leaf spot and rust due to low inoculum potential whereas late sown crops suffered more because of ready availability of inoculum built in early sown crops (Naidu and Chandrika, 1997). Further they also suggested that late *Kharif* sowing might be utilized for screening groundnut germplasm for disease resistance due to the existence of maximum inoculum load on the late sown crop. Similarly, Ashtaputre *et al.* (1994) found that early sowing preferably in June helped in the reduction of late leaf spot incidence. Kumar *et al.* (2010a) studied the effect of soil and irrigation water salinity on severity of major foliar fungal diseases of groundnut and found that salinity stress reduced the foliar fungal diseases *viz.*, early leaf spot, late leaf spot and rust. It was concluded that though groundnut was a sodium sensitive crop to soil salinity, it can be grown profitably up to a threshold salinity stress of 2.0 dS m^{-1} irrigation water salinity (EC_{iw}) and 2.5 dS m^{-1} soil salinity as at this salinity the severity of foliar diseases were less and the pod yield was maximum.

Host resistance

Use of disease resistant cultivars is one of the best means for reducing crop losses. Sources of disease resistance have been identified both in the primary gene pool and in the wild relatives of *A. hypogaea*. Hundreds of land races, advanced breeding lines, cultivars and wild species have been screened for resistance against foliar fungal diseases by several workers and a large number of resistant sources have been identified (Ghewande *et al.*, 1992; Mc Donald *et al.*, 1985; Moraes and Godoy, 1985; Subramaniyam and Mc Donald, 1987; Subramaniyam *et al.*, 1989). Source of multiple disease resistance especially for late leaf spot and rust are also available from ICRISAT. These are EC76446

(292), NCAc17133 (RF), PI 259747, PI 350680, PI 389595, USA 63 and NCAc 343. Ghewande *et al.*, 1992 identified five multiple disease resistant germplasm accessions *viz.*, NCAc17149, NCAc927, NCAc17133 (RF), PI 393646 and PI 341879, resistant to early leaf spot, rust and *Alternaria* leaf spot. Recently, Bera *et al.* (2011a,b,c,d,e,f,gh) reported eight groundnut germplasm *viz.,* NRCGCS 77, NRCGCS 83, NRCGCS 85, NRCGCS 86, NRCGCS 21, NRCGCS 124, NRCGCS 180, and NRCGCS 222 having multiple disease resistance to PBND, stem rot, late leaf spot, early leaf spot, rust and Alternaria leaf blight. Genetic resistance to foliar diseases such as *P. personata* and *C. arachidicola* has usually been associated with low yields and late maturity (Pixley *et al.*, 1990). The genotypes, ICGV 86252 and JL 24-3 were found resistant to leaf spot in field trials (Reddy *et al.*, 1997). In general, it is very difficult to get promising sources of resistance to many of the seed and soil borne pathogens such as *S. rolfsii, M. phaseolina* and *A. niger* as they are not very specialized pathogens and they have a very wide spectrum of host attacking mechanism. However, a few genotypes have been identified as tolerant to these pathogens. Recently an advanced breeding line, NRCGCS 19 at NRCG had been found resistant to stem rot and incorporation of resistance from this to agronomically suited variety is in progress (Ghewande *et al.*, 2003). At ICRISAT, ICGV 86029, ICGV 86030, ICGV 86031, ICGV 86032, ICGV 86033 and ICGV 86558 were identified to possess field tolerance to groundnut bud necrosis and also had good agronomic traits (Reddy *et al.*, 1991). *Arachis chacoense* and *A. pussilla* were found to be resistant to peanut mottle virus (Reddy, 1988). Two genotypes *viz.* EC-76446 (292) and NCAc 17133 RF had not shown any seed transmission of peanut mottle virus (Ghanekar, 1980). Four genotypes JSP 1, ICGMS 2, NCA X and CGC 4 have been reported to be resistant to root knot disease caused by *M. arenaria* (Grewal *et al.,* 1986). The released varieties resistant / tolerant to major diseases are listed below which continues to be used in endemic areas.

Diseases	Resistant/tolerant varieties
Early leaf spot, late leaf spot, rust	ALR 1, ALR 2, ALR 3, Girnar 1, ICGV 86590, ICGV 87160, ICGV 86325, CSMG 84-1, OG-52-1, RSHY 1, DRG 12, DRG 17, TAG 24, BSR 1, VRI 5, CO 4
Collar rot and aflaroot	J 11, JCG 88 and OG-52-1
Stem rot	OG-52-1, Dh-8, and ICGV 86590
Groundnut bud necrosis disease	ICGS 11, ICGS 44, ICGS 37, Kadiri 3, ICGV 86325, K 134, DRG 12, R 8808, JCG 88, CSMG 884

Source: Ghewande *et al;* 2002.

Biological control

Biological control refers to the purposeful utilization of introduced or resident living organisms to suppress the activities and populations of one or more plant pathogens. A critical analysis of the literature on biological control reveals a skewed research towards soil-borne pathogens, as the response has been more positive in this area as compared to foliar pathogens. The biocontrol agents have to be produced in bulk and applied with the onset of the disease to get the desired level of control. Mass production of biocontrol agents using low cost technology is the basic requirement for successful exploitation of biocontrol agents.

Among the fungi, *Trichoderma* has been extensively used to manage a variety of plant pathogens. The genus *Trichoderma* has nine species aggregates with a lot of strains. The mode of biocontrol is by mycoparasitism, competition, production of hydrolases and antimicrobial chemicals. Whereas some strains possess more than one mode of action and effective against many pathogens, some strains are specific to some pathogens. Several strains of *Trichoderma* have been commercially exploited and are available for use by farmers. *T. harzianum* and *T. viride* applied as seed dressing effectively reduced mortality of groundnut seedlings due to stem rot and collar rot (Kulkarni *et al.*, 1994; Nagaraju and Urs, 1998). Seed rot and collar rot were reduced in pot cultures when *Trichoderma* isolates were incorporated into the soil (Prabhu and Urs, 1998). The spores of *Trichoderma* remained viable up to nine weeks of storage at room temperature on seeds when the seeds were coated and reduced the stem rot incidence (Biswas *et al.*, 2000). Biswas *et al.* (2000) reported significant reduction in stem rot incidence by two strains of *Trichoderma* either as seed dressing (33-50%) or soil application in pot trials (72-83%). Their studies on formulation of the strains showed that spores of T8 and T10 isolates showed better longevity after 13 weeks (1.3×10^3 *c.f.u.*/seed) and upto 15 weeks (1.0×10^4 *c.f.u.*/seed) respectively, when the seeds coated with spores were dipped in 2% carboxy methyl cellulose and pelleted with bentonite at 25 g/kg seed. Bacterial isolates *viz.* BCB-135, AF-52, *Pseudomonas fluorescens*-2 and *Bacillus* isolates were effective in reducing the population of *A. flavus*. *Bacillus* spp. could reduce the population by 53.08% followed by *P. fluorescens* (47.94%), AF-52 (40.60%) and BCB-135 (36.56%). These isolates also showed plant growth promotion activity (Desai *et al.* 2002).

Rust was significantly reduced by *T. harzianum* on detached groundnut leaves. *T. harzianum* colonized better on uredosori (16 day old) which were post treated with the antagonist than on pustules developed on pre-treated and simultaneously treated leaves. A phenol-like antifungal compound was separated from the 36 hr old germinating *T. harzianum* (Govindasamy and Balasubramanian, 1989). The mycoparasites like *Acremonium persicinum*, *Eudarluca caricis*, *Penicillium islandicum*, *Tuberculina costaricana* and *Verticillium lecanii* and their culture filtrates inhibited urediniospore germination and reduced rust development by varying degrees. Sprays of culture filtrates of *V. lecanii* and *P. islandicum* significantly reduced rust disease under field conditions (Ghewande, 1990b). By monitoring the fermentation conditions, biocontrol agents against late leaf spot and rust such as *P. islandicum* and *V. lecanii* were mass multiplied and formulated using cheap and simple substrates (Desai and Bagwan, 2002). Another antagonist *Fusarium chlamydosporum* has been found to rapidly colonize the rust pustules. Mathivanan and Murugesan (2000) found that uredospore greatly lost its ability to germinate and also resulted into bursting and degradation of cell walls of uredospores. A significant reduction (20-38%) was recorded due to spraying of culture filtrates along with uredospores.

Extra cellular chitinolytic enzymes of microorganisms have a potential to suppress the activities of the pathogens by degrading the chitin in their cell walls and thus protect the plants from disease. A 40 kDa extra cellular chitinase was detected from *M. verrucaria*, an antagonist of *P. arachidis*, and the purified chitinase inhibited uredospore germination (Govindasamy *et al.*, 1998). Kishore *et al.* (2003) found that *Serratia marcescens* GPS-5 and *Bacillus circulans* GRS-242 had potential in terms of chitinolysis and inhibition of *in vitro* conidial germination of *P. personata* when these strains were used as foliar spray in controlled environment, reduction in late leaf spot was non-significant but supplementation of foliar spray with 1% colloidal chitin resulted in effective control. Mycoparasites, *Dicyma pulvinata* and *V. lecanii*, and their culture filtrate inhibited the *in vitro* spore germination (33-75%) and reduced *in vivo* development of *P. personata* (Ghewande, 1989b).

Among bacterial antagonists, species of *Pseudomonas* are known to be highly potential. Fluorescent pseudomonads have been reported to be antagonistic against many soil-borne and foliar pathogens. Podile and Prakash (1996) have studied in detail the mode of action of *B.*

subtilis AF1 strain, effective against *A. niger*. The bacterial cells adhered to the fungal mycelium, multiplied *in situ*, colonized and lysed mycelial surface. Groundnut seeds bacterized with *B. subtilis* showed a reduced incidence of crown rot in *A. niger* infested soil. Patil *et al.* (1998) reported that two strains of *Pseudomonas fluorescens viz*. FPD-10 and FPD-15 inhibited sclerotial germination of *S. rolfsii in vitro* as well as in soil. The strain FPD-15 was more 'ecologically fit' with greater multiplication and survival in the soil. Among six carriers tried for the soil application of a native isolate of *Pseudomonas fluorescens* for the management of *A. niger,* disease incidence was the lowest (23.33%) in the peat soil followed by the farmyard manure and *gobar* gas effluent (Sheela *et al.*, 1998). Bacteriarization with species of *Bacillus* resulted in the effective biological control of stem rot of groundnut and enhanced plant growth/yield (Sakthivel *et al.*, 1998). *B. subtilis* AF1 not only inhibited *A. niger* causing collar rot but also possessed plant growth promoting activity (Sailaja *et al.*, 1998). Hence, the isolate could be used for management of *A. niger.* Kishore *et al*. (2005) reported suppression of collar rot by *Pseudomonas aeruginosa* strain GSE 18 and the cell-free culture filtrates were fungicidal and induced mycelial deformations including hyphal bulging and vacuolization in necrotrophic fungi. Rakh *et al.* (2011) reported antagonistic activity of *Pseudomonas cf. monteilii 9* against *S. rolfsii*. It produced diffusible antibiotic, volatile metabolites, hydrogen cyanide and siderophore which affected *Sclerotium rolfsii* growth *in vitro*.

Botanicals

Green plants appear to be the reservoirs of effective therapeutants and can provide renewable sources of useful biofungicides. For example, aqueous leaf extracts (2%) of neem (*Azadirachta indica*) and mehandi (*Lawsonia inermis*) were found to be effective and economical in controlling leaf spots and rust diseases of groundnut (Ghewande, 1989a). Neem has been extensively used for the management of diseases of crop plants. However, in groundnut use of neem and its products has not been very extensive. In the field trials conducted at the DGR, Junagadh during *kharif* 1985-86 and 1989-90, three sprays of aqueous neem leaf extract (2%) at fortnightly interval starting from 4-5 weeks reduced severity of early leaf spot by 13.6%, late leaf spot by 22.2% and rust by 30.6%. The treatment also increased the pod yield by 26.1% with a benefit/cost ratio of 2.26:1. Ganapathy and Narayanaswamy (1990) reported that water extracts of neem leaf, neem cake and neem oil (1%) was useful in inhibiting the LLS and rust pathogens under

laboratory conditions. They also reported that 1% neem oil reduced the incidence of LLS and rust and increased pod yields by 62.3% of groundnut over control. Soil application of 55 kg/ha potash plus 1% foliar application of potash coupled with 2% neem seed kernel extract significantly reduced the incidence of tikka leaf spot and increased pod and haulm yield (Chandrasekhar *et al.*, 1994). On the contrary, Lokhande *et al.* (1998) have found that chemical spray was superior to neem products. Such differences in the performance of plant products is not unusual as the efficacy of broad spectrum pesticides such as neem depend on the initial inoculums load of the pathogens, the weather prevailing at the time of spray and efficacy of the formulation. Usually, when the disease levels are already high, such pesticides show little influence in disease control. *A. niger, M. phaseolina,* and *A. flavus* were effectively controlled by the extracts of *Polyalthia longifolia* (Sobti *et al.,* 1995). Narain *et al.* (1981) found that soaking groundnut seed in *Vinca rosea* leaf extract was not as effective as that of carbendazim and thiram to reduce leaf spot incidence. Ethanol and essential oil extracts of *O. sanctum* inhibited growth and multiplication of *A. niger* and *A. flavus* and increased seed germination of groundnut. In greenhouse studies ethanol extracts gave the best control of both diseases (Mahapatra *et al.*, 1994). Spraying of 2.5 g mancozeb + 1.0 g carbendazim at 50 DAS followed by spraying of *C. procera 5%* leaf extract at 70 DAS proved to be highly significant in reducing the leaf spot disease and in increasing the yield (Srinivas *et al.*, 1997). Leaf extracts of coconut, sorghum, neem and *Parthenium* reduced the late leaf spot incidence and increased the yield, neem leaf extract being the most effective. (Sudheendra-Ashtaputre, 1999). Application of mustard cake @ 2% enhanced the growth of *Trichoderma* spp., where as germination of sclerotia of *S. rolfsii* were inhibited at the same concentration (Desai *et al.,* 2003). Growth of *S. rolfsii* was effectively inhibited by all the concentrations tested of the extracts of *Agave americana*, *Cassia occidentalis* and *Azadirachta indica*, the maximum inhibition being at 10% concentration (Seshakiran and Adiver, 2003). Two years field experiments (2001-2002) showed that application of fresh leaves of *Parthenium hysterophorus*, neem, *Pongamia glabra* and wild sorghum @500 kg/ha in furrow at the time of sowing gave higher yield and effective control of stem rot as compared to control treatment (Ghewande *et al.*, 2003).

Chemical Methods

Several systemic and non-systemic fungicides were tried for reducing the severity of major foliar diseases *viz.* early leaf spot, late leaf spot and rust in India and elsewhere (Kolte, 1984; Mc Donald *et al.*, 1985; Subramaniyam and Mc Donald, 1987). However, no single fungicide was found effective against all the foliar diseases. Efforts were made to evaluate new chemicals released from time to time for their efficacy against groundnut pathogens. However, as seen from the overall analysis, most of the studies found that carbendazim was effective against leaf spots and mancozeb to the rust disease. This also probably gives an indication that there is not considerable variability in the pathogens. Singh and Naik (1977) reported efficacy of two sprays of carbendazim and benomyl in managing leaf spots and in increasing yield. In field trials at two locations, application of three foliar sprays of 0.2% mancozeb or kocide (copper hydroxide) or 25 kg sulphur dust/ha at 15-day intervals beginning 45 days after sowing, was effective against *P. arachidis* and increased yields of unshelled nuts from 459 to 764-996 kg/ha. Mancozeb was the most effective, followed by sulphur dust and kocide (Durairaj and Mohan, 1978). Three years of study revealed that three sprays of tridemorph at 0.07%, beginning 45 days after planting and continuing at 10-day intervals, gave effective control of rust and increased pod yield (Mayee *et al.*, 1979). In field trials, four sprays of carbendazim at 150 g in 250 L water/ha, at fortnightly intervals, substantially decreased leaf spots and increased yield. However, it was also suggested that to avoid development of resistance, the last spray should be made with a different non-systemic fungicide (Sekhon and Dhillon, 1981; Rattan and Kang, 1984). Three sprays of carbendazim (0.1%), benomyl (0.1%), copac (0.1%), tridemorph (0.05%), mancozeb (0.2%) and propiconazole (0.1%) reduced intensity of leaf spots and rust and increased the pod yield significantly (Rahman *et al.*, 1989). However, carbendazim and tridemorph were best against leaf spots and rust, respectively. Adiver and Anahosur (1995) reported tebuconazole, cyproconazole, propiconazole and difenoconazole were effective against late leaf spot. Best control of leaf spots and rust was achieved with hexaconazole and difenoconazole, and these treatments also gave highest pod and fodder yields. Spraying of a mixture of mancozeb and carbendazim at 50 days after sowing, followed by spraying of 5% leaf extract of *C. procera* at 70 DAS proved to be highly significant in reducing the leaf spot disease and in increasing the yield (Srinivas *et al.*, 1997). Leaf spots and rust were effectively managed when three sprays of carbendazim (0.05%) + mancozeb (0.2%) were

given at 15 days interval commencing from the first appearance of symptoms (Naidu and Rao, 1997). Johnson *et al.* (1998) reported spray treatments of carbendazim + mancozeb gave good control of foliar diseases with an increase in yield by 20%, giving an additional income of Rs. 2250 per hectare. Rust and leaf spots were substantially reduced by spraying a mixture of carbendazim (0.025%) and tridemorph (0.4%) five times at fortnightly intervals commencing 35 days after sowing during summer. The hexaconazole treated plots gave a 71% higher pod yield and an 87% higher fodder yield than an untreated control with the highest net return of Rs 9793/ha (Jadeja *et al.,* 1999). Instead of taking up spray schedules based on crop age, Das *et al.* (1997) used weather dependable spray schedule (WDSS) to minimize application to only two sprays for management of leaf spots and rust. Such schedule would be highly useful in areas where the disease is endemic and the variety sown is susceptible.

For management of seed and soil-borne diseases only seed treatment has been practical as soil application of chemicals has not only been expensive but also not practical. carbendazim @ 2 g/kg of seed was recommended for the control of collar rot. Seed treatment with either thiram @ 3 g/kg seed or carbaendazim @ 2 g/kg seed is effective in controlling seed and soil-borne diseases. Among 12 fungicides screened, propiconazole and iprodione at 5-1000 ppm inhibited the mycelial growth and also controlled spore production of *A. niger* (Woothisak *et al.,* 1991). Tok-E-25 was the most effective treatment in controlling *A. niger* and *A. flavus*, *in vitro* (Siddaramaiah *et al.,* 1981). Tebuconazole and cyproconazole were effective against *S. rolfsii*, which inhibited ergosterol biosynthesis (Adiver and Anahosur, 1995).

In addition to traditional antifungal chemicals, efforts were made to use chemicals that induced resistance in the plant systems. Dasgupta *et al.* (1998) found that seed soaking in chitosan (0.1%) is economical in controlling collar rots. Chitosan treatment of groundnut leaves before inoculation reduced the number of lesions, lesion diameter and sporulation of *P. arachidis* (Sathiyabama and Balasubrahmaniam, 1998). Further it was observed that chitosan-treated leaves showed an increase in endogenous salicylic acid and intercellular chitinase and glucanase activity which were associated with induced resistance. A mixture of Di-xiu-na (a.i. sodium sulphanilate) and colloidal sulphur controlled infection of rust and leaf spot pathogens, increasing yield by 30-40%. Addition of 0.1% copper sulphate to the spray improved

efficiency. To avoid phytotoxicity, concentration of Di-xiu-na should not exceed 1:500, or 1:600-700 at high air temperature. The mixture controlled rust well even in the rainy seasons (Lin and Cheng, 1980).

Biotechnological approaches

The rate of success in conventional disease resistance breeding in groundnut had been very low in India. Though some good sources of resistance to foliar diseases are available (Subramaniyam *et al.*, 1995), a very high degree of resistance could not be transferred to the high yielding background mainly because of the complexity of inheritance of resistance and undesirable linkages (Millar *et al.*, 1990). Wild relatives of groundnut possess resistance to the level of even immunity. But, the interspecific hybridization has not been highly successful in introgressing the desirable traits due to several inherent breeding barriers (Bandyopadhyay *et al.*, 1992). Though a moderate degree of resistance against aflatoxigenic fungi is available in the cultivated gene pool, success in breeding has been almost non-existent. Relatively little efforts have been made so far in breeding for resistance to the soil-borne pathogens. In addition, the breeders have been using a very limited stock of the primary gene pool (Stalker, 1991). To add to this problem, isozyme and restriction fragment length polymorphism (RFLP) have shown that variability at the molecular level is low in cultivated groundnut (Kochert *et al.*, 1991). This limited variability may explain to some extent why the groundnut yield is not going over the plateau. Therefore it becomes imperative to explore at least the alternative possibilities of building up host resistance as a part of integrated disease management.

Through the aids of non-conventional breeding methods like transformation and protoplast fusion, disease resistance could be introduced into an otherwise desirable genetic background. The success of these methods has started generating good hopes in the case of virus diseases where coat-protein-mediated resistance has been used. For a successful non-conventional gene transfer programme, the basic requirements are standard and easily reproducible *in vitro* regeneration and recombination techniques. In groundnut, protocols have been standardized for regeneration (Ozias-Akins *et al.*, 1993; Bandyopadhyay *et al.*, 1995). Chitinases and glucanases are two potential classes of enzymes, which can hydrolyze the cell walls of the pathogenic fungi (Bama and Balasubramaniam, 1991; Buchala *et al.*,

1991). The chitinase III, isolated from rust infected leaves, inhibited germination, germ tube growth and appressoria formation of *P. arachidis* uredospores (Govindaswamy and Balasubramaniam, 1994). Infection of groundnut leaves with *C. arachidicola* lead to a marked increase in activity of three extra cellular β-1, 3 glucanases, which when acting together, were capable of degrading the pathogen cell wall *in vitro* (Roulin and Buchala, 1995). In groundnut, chitinase genes form a small multigene family. Herget *et al.* (1991) isolated four chitinase cDNAs (*chit* 1-4) from cultured cells. Expressions of individual *chit* genes were assayed by the polymerase chain reaction followed by RFLP analysis. They concluded that *chit 2* gene expression may be controlled by pathogen-specific regulatory elements as the expression was strongly activated by the cell wall components of *Phytophthora megasperma.* Kellmann *et al.* (1996) characterized, cloned and sequenced two classes II chitinases from groundnut cv. NC4 (*A.h.Chi2; 1* and *A.h.Chi2; 2*). Transgenic tobacco plants containing the complete peanut *A.h.Chi2;1* gene exhibited essentially the same expression pattern in leaves as observed in peanut cell cultures. Transcriptional fusion of a 1.2 kb 5'-upstream region of *A.h.Chi2; 1* to the GUS reporter gene conferred its expression in leaves of transgenic tobacco plants after challenging with *P. megasperma* elicitor or *Botrytis cineria* spores. Thus, the chitinase gene system offers, apparently, a way for building up of resistance to fungal pathogens of groundnut. Such resistance, if successful, may be durable being non-specific in nature. Fertile transgenic plants of groundnut cv. TMV-2 expressing tobacco (*Nicotiana* spp.) chitinase gene were generated. The transgene stably integrated in the genome of peanut plant and inherited in offspring. Small-scale field tests indicated increased ability of these plants to resist the fungal pathogen, *C. arachidicola* (Rohini and Rao, 2001). Somaclonal variants of groundnut having higher biomass and field tolerance to leaf spot and rust disease were selected in fourth generation from shoot tip regenerants of groundnut variety TAG-24. Field testing of the regenerants revealed that the characters are stable and heritable (Eapen *et al.*, 1999).

Against soil-borne fungal pathogens of groundnut, relatively less work has been done mainly due to lack of information on nature of disease resistance against pathogens such as *Sclerotium rolfsii, Aspergillus* spp., *Macrophomina phaseolina* and *Rhizoctonia solani.* The role of phytoalexins in groundnut disease resistance was reviewed by Strange and Subba Rao (1994) and Daniel and Purkayastha (1995). The information can

help to track down the phytoalexin production metabolism so that the genes for the synthesis of these phytoalexins could be isolated and used. *Trichoderma* spp. are the most studied among the various biocontrol agents studied so far. However, they have not been successful as a part of integrated disease management for several reasons. The absence of more than one mode of action in a single strain may be one of them. Efforts were thus made for cataloguing of the strains of *Trichoderma* for various desired traits to introgress the desirable traits into an otherwise desirable strain of the biocontrol agent (Desai, 1996). However, Stasz *et al.* (1989) found limited vegetative compatibility between and within the species of *Trichoderma* following protoplast fusion. Sivan and Harman (1991) developed intraspecific hybrids of *T. harzianum* Strain 1295-22, derived from fusing protoplasts of auxotrophic mutants of the prototrophic strains T12 and T95, was more effective in colonizing the middle sections of the roots than either of the parental strains. Protoplast fusion in the genus *Trichoderma* gives rise to great variability (Stasz *et al.,* 1989; Stasz and Hannan, 1990). To enable marker-assisted selection, protocols were standardized for transformation of spores of *Trichoderma* spp. by electroporation for the introduction of marker characters (Desai, 1996). Similar efforts were made in the past also by Sivan *et al.* (1992) to introduce *Hyg*B gene conferring resistance to hygromycin B in *T. viride* and *T. harzianum* including the details of selection protocols, regeneration of transformants and chromosomal integration of *Hyg*B gene. Lorito *et al.* (1993) compared efficiency of biolistic and protoplast-mediated procedures to transform strains of *Gliocladium virens* and *T. harzianum.* The biolistic procedure was technically simpler which increased the transformation frequency and genetic stability in the progeny as compared to the protoplast-mediated transformation. Electrofusion protocols were also standardized for intra- and inter- specific hybridization of protoplasts with a view to introgress the desirable traits to enhance biocontrol ability (Desai, 1996).

Cole *et al.* (1988) hypothesized that phytoalexins were involved in resistance to moisture-deficit-stress induced preharvest aflatoxin contamination of immature groundnuts and this resistance might have evolved in an ecosystem that included seasonal periods of moisture-deficit-stress. Cooksey *et al.* (1988) identified a stilbene (3 isopentadienyl l-4, 3′, 5'-trihydroxystilbene) as the major antifungal component elicited by slicing imbibed kernels. The compound was inhibitory to both spore germination and hyphal extension of *A.*

flavus. The invasion of groundnut kernels by *A. flavus* can occur under many conditions, but aflatoxin contamination does not occur until kernels lose the capacity to produce stilbenes as a result of moisture-deficit-stress induced dehydration (Cole and Dorner, 1993). The biosynthesis of stilbenes was due to the activity of two enzymes *viz*. stilbene synthase, which catalyses a one-step reaction to phytoalexins from precursors present in all plant cells, and a reductase, which in co-action with [naringenin-] chalcone synthase channels the metabolite flow into the biosynthesis of isoflavonoid phytoalexins (Schroder *et al.,* 1993). The preliminary evidence of the possibility of stilbene-gene amplification had been obtained. Fisher and Hain (1994) generated transgenic tobacco plants expressing, (trishydroxyl) stilbene synthase genes from groundnut resulting in pathogen-inducible resveratrol synthesis. Glutathione-S transferase (GSH) is a constitutive enzyme of the plants. It has a major role in imparting herbicide resistance to the plants. Aflatoxins are oxidatively metabolized by the oxygenase system localized on endoplasmic reticulum forming an unstable but highly reactive AFB_1-8, 9 epoxide. The levels of GSH in mice are high enough to convert 12 times more AFB_1-8,9 epoxide to AFB_1-GSH and hence are resistant to the carcinogenic effects of AFB_1 compared with male rats (O'Brien *et al*., 1983; Ramsdell and Eaton, 1990). The genes for GSH have already been cloned in maize. Attempts could be made to produce transgenic with GSH genes in groundnut. This could be another possible approach to manage aflatoxin contamination (Keenan and Savage, 1995). ICRISAT, Hyderabad has developed specific monoclonal antibodies for estimation of aflatoxin. Besides this transgenic groundnut against Indian peanut clump virus (IPCV) using coat protein (*Cp*) gene has been produced. The field testing of IPCVcp transgenic is underway. cDNA copies of the *Cp* gene of (IPCV)-H were introduced into cells of *Nicotiana benthamiana* or *Escherichia coli* by transformation with vector based on pROK II or pET, respectively. The IPCV *Cp* was expressed and assembled to form virus-like particles. When transgenic plants expressing IPCV-H *Cp* were inoculated with IPCV-L, a strain that is serologically distinct from IPCV-H, the virus particles that accumulated contained both types of *Cp* (Bragard *et al*., 2000).

Integrated disease management

It is evident from the literature that there is a great scope for integration of suitable and compatible disease control measures for the

development of an integrated disease management (IDM) package. IDM is an optimum blend of feasible and economically viable options of disease management for different agro-climatic regions depending on the occurrence and importance of the disease. Gorbet *et al.* (1990) successfully used host plant resistance along with fungicides for the control of leaf spots. Barnes *et al.* (1990) integrated fungicides, genotypes, cultural practices (irrigation) and environment to control *Rhizoctonia* limb rot and stem rot. They reported that the application of difenoconazole every 14 days at 0.28 kg a.i./ha on 'Florunner' and 'New Mexico Valencia' cultivars with reduced irrigations resulted in maximum reduction of the limb rot. Combining 'Southern runner', a moderately resistant variety to late leaf spot, *S. rolfsii* and tomato spotted wilt virus with applications of chlorothalonil could provide late leaf spot control (Culbreath and Brenneman, 1992). At DGR, Junagadh, various control measures were integrated for the management of early and late leaf spot. Early and late leaf spot control was achieved where groundnut was intercropped with pigeon pea and sprayed twice (55 and 70 DAS) with a mixture of fungicides (carbendazim 0.05% + mancozeb 0.2%) or where groundnut was intercropped with pigeon pea and received one spray each of neem leaf extract (2%), fungicide mixture, and cell-free culture filtrate of *P. islandicum* at 45, 55 and 70 DAS, respectively. These treatments, and groundnut intercropped with pigeon pea and sprayed separately with neem leaf extract and *P. islandicum* inoculums at 55 and 70 DAS gave significantly higher net monetary returns (₹ 9569-11561 /ha) with cost: benefit ratio ranging from 1:2.99 to 1:3.63 for 'Girnar 1' and 1:2.67 to 1:3.48 for 'JL-24' cultivars (Ghewande *et al.*, 1993). Karthikeyan (1996) reported the ability of organic amendments (neem cake, mahua cake, castor cake, farm yard manure, sheep manure and poultry manure), the biocontrol agent (*T. harzianum*) and fungicides (carbendazim and thiram) to control seed and collar rot (*A. flavus* and *A. niger*) of groundnut. The lowest disease incidence was recorded when carbendazim was applied as a seed treatment. A soil application of *T. harzianum* was also effective. Of the organic amendments, neem cake and farmyard manure gave good disease control. These treatments also increased the yield of groundnut crop. Srinivas *et al.* (1997) found that spraying of 2.5 g mancozeb + 1.0 g carbendazim at 50 DAS followed by spraying of *Calotropis procera* 5% leaf extract at 70 DAS was highly significant in reducing the leaf spot disease and increasing the yield. Seed treatment with *P. fluorescens* @ 10 g/kg seed + soil application of neem cake @ 160

kg/ha before sowing was found to be the best treatment in reducing collar rot incidence, however, seed treatment with *T. viride* @ 4g/kg seed +soil application of neem cake gave higher pod yield (₹ 1849 kg/ha) which was next best treatment for reducing incidence of collar rot (Sheela and Packiaraj, 2000). On-station experiments on IDM at ICRISAT have clearly demonstrated that when moderate levels of host plant resistance are combined with seed treatment and affordable levels of chemical control, expected yields and economic returns are higher than obtained with chemical control of susceptible genotypes (Pande *et al.*, 2001). Soil application of castor cake @500 kg/ha + commercial preparation of *T. viride* (Monitor-S) 62.5 kg/ha in furrow at the time of sowing reduced the incidence of collar rot and stem rot of groundnut considerably and gave higher gross monetary return of ₹ 29865 /ha than farmers practice (₹ 23685 /ha) under the IVLP-TAR programme (Dr. M.P. Ghewande, personal communication).

In an UNDP sponsored project on "Promising Groundnut as Food Crop for Sustained Nutritional Security" Basu (2001) demonstrated the strength of integrating pre- and post-harvest factors in reducing aflatoxin risk through farmers' participatory research mode. Combination of critical pre- and post-harvest factors at soil, plant and storage levels reduced aflatoxin risk substantially (0-5 $\mu g\ kg^{-1}$) in large number samples and 78% were made safe to eat even in a high risk area. The storage aspects of the produce at farmers level and aflatoxin build up under ordinary storage condition over a period of three months were monitored in Anantapur district and various storage practices were studied to keep aflatoxin B_1 within the prescribed limit from the health point of view (Basu, 2001). Kumar *et al.* (2002) evaluated an integrated management package to reduced pre-harvest seed infection by *A. flavus* in groundnut. Seed infection studies revealed predominance of *A. flavus* infection in plots under farmers' practice (10%) compared with that under integrated aflatoxin management package (2%). An integrated approach giving the handy guidelines for farmers, traders, and processors to safeguard groundnut from aflatoxin contamination was described by Kumar *et al.* (2005). Further, Kumar *et al.* (2009) evaluated an integrated management practice with farmers' participation in different villages of Junagadh and Amreli districts of Gujarat. The integrated management practice (IP) was compared with farmers' practice (FP). The IP which comprised of summer ploughing, seed treatment with carbendazim, furrow application of castor cake enriched with *Trichoderma* at sowing,

application of gypsum at flowering, spray applications with carbendazim plus mancozeb and the neem oil, harvest at optimum maturity and sorting of pods was superior to FP which, comprised of all agronomic practices (seed, fertilizer, interculturing etc) excepting the inputs of IP. The IP was effective in reducing the soil population of *A. flavus*, seed infection and colonization and the aflatoxin contamination. The yield was also significantly high in the IP plots with an incremental cost benefit ratio (ICBR) of 1.68. At post-harvest and processing level, on-site study conducted with bulk groundnut lot revealed that the blanching used in conjunction with manual and electronic sorting was very efficient in removing aflatoxin-contaminated kernels (Kumar *et al.,* 2010b). A sequential sorting of bulk groundnut lot now being practiced by a few Indian industries using mechanical screening, electronic eye sorting followed by manual sorting of discoloured kernels is a good measure to get final products practically free from aflatoxins.

Based on the results of research and the various options that are in hand, the following guidelines for integrated management of major diseases are listed which may be followed suitably for the location specific problems:

- Undertake deep ploughing (8-10 inches) to invert the soil and expose the soil to sun for 2-3 weeks for soil solarisation.
- Deep burying of crop residues, destruction of crop debris by burning, removal of volunteer groundnut plants
- Follow recommended agronomic practices for land preparation, seed rate, spacing, fertilizer and irrigation management and keep the field free from weeds
- Sow only sound seeds and treat them with carbendazim @ 2g/kg one week before sowing or with commercial formulations of *Trichoderma harzianum* or *T. viride* @ 4g/kg seed just before sowing.
- Apply neem or castor cake @ 500 kg/ha in furrow at the time of sowing. If cakes are too dry, sprinkle little water and mix 2.5 kg of commercial formulation of *Trichoderma* and keep the mixture in shade for about a week before applying to the soil.
- Early sowing (wherever possible) with wider inter rows spacing (40 to 45cm) for managing early leaf spot, late leaf spot and rust but close spacing (20 x 10 cm or 30 x 7.5 cm) wherever stem rot and PBND is a serious problem.
- Early sowing the crop (first fortnight of June) for peninsular and

central India but late sowing (first fortnight of July) for Northern India for the management of PBND.

- Crop rotations with cotton, wheat, maize, jowar, onion, garlic especially wherever stem rot is a serious problem.
- Intercropping with pearl millet, sorghum, pigeon pea and maize for the management of foliar diseases and pearl millet for management of thrips, leaf miner and PBND.
- Spray neem seed kernel extract (NSKE) @ 5% or crude neem oil in teepol @ 2% against defoliators, mites and foliar pathogens.
- Need based application of fungicides *viz.* two spray of 0.2% mancozeb at 35 and 70 days after germination and one spray of 0.05% carbendazim at 60 days after germination, or application of carbendazim (0.025%) + tridemorph (0.04%) five times at fortnightly intervals commencing 35 days after sowing during summer season, or spray of carbendazim (0.05%) + mancozeb (0.2%) at 2-3 weeks interval, 2 or 3 times starting from initiation of the disease, or spray once with chlorothalonil @ 0.2 to 0.3% just after the appearance of the first visible symptoms of foliar diseases like rust and leaf spots.
- Need based application of insecticides *viz.*, chloropyriphos EC 0.05% or phosalone 0.05% or cypermethrin 0.009% or quinalphos 0.05% for defoliators, and spraying of fipronil 5% SC @1.500-2.000 ml/ha or thiacloprid 21.7% SC @125 ml/ha or thiamethoxam 25% WG @ 40 g/ha or dimethoate 30 EC @ 2 ml/l of water at 25, 45 and 60 days after sowing will protect the crop from sucking pests including thrips menace.

In addition to above practices, to contain aflatoxin contamination in groundnut following management strategies may be adopted at different stages:

a. Pre harvest stage

1. Apply well decomposed farmyard manure/compost @ 5-10 tonnes/ha, if available.
2. Inter-row water harvesting by adopting paired row method of planting.
3. Select short/medium duration variety, which can escape end of season drought at maturity. Advance sowing by a fortnight with a pre-sowing irrigation to evade end- of- season drought.
4. Apply gypsum @ 400-500 kg/ha at flowering.
5. Avoid end-of-season drought by providing supplemental irrigation.

6. Harvest the crop at right maturity (blackening of inner surface of shell).

b. Harvesting and post-harvest stage

1. Hot spots, the patches of field that have undergone stress or harboured diseases should be harvested, dried, stocked and disposed off separately.
2. Avoid mechanical damage to the pods during harvesting.
3. Dry the uprooted plants along with the pods in small heaps by keeping them up-side-down. Dry the plants till the leaf/pegs become brittle (6-7 days).
4. Pick the immature pods first and do not mix them with the main lot of mature pods. If mechanical thresher is used, appropriate sieves should be used to isolate immature pods.
5. Remove all the pods showing mechanical or insect damage.
6. Dry thoroughly the sound pods to a safe moisture level of 8%. Well-dried pods produce rattling sound on shaking a handful of pods.
7. Store the produce in new/clean polythene lined gunny bags and stack them on wooden planks keeping a metre gap from the walls in a well-aerated and well-covered space.
8. Keep the storage space free from any kind of seepage or leakage water that may lead to build up of moisture.
9. Prevent insect damage to the pods in storage by fumigating with phosphene (use 3-5 aluminium phsophide tablets for every 100 kg of pods for 7-8 days).
10. Primary sorting of groundnut pods before processing.
11. Improving post-harvest processing technologies *viz*., blanching, sorting of kernels with camera or laser sorter.

Future research needs

The diseases like rust, leaf spots and contamination of aflatoxins continued to be serious problems associated with groundnut crop. To this list, other important problems such as collar rot, stem rot, Alternaria leaf blight and groundnut bud necrosis disease now got prominence and need attention of plant pathologists as well as breeders. Some of the future line of research in this direction would be:

1. Testa level resistance against *A. niger, A. flavus* and *S. rolfsii* under *in*

vitro conditions doesn't corroborate with field resistance. Further, the resistance level changes over the years making it difficult to have a breakthrough in developing a cultivar with stable resistance, particularly against *A. flavus* and aflatoxin contamination. Development of non-destructive rapid screening technique against these pathogens in addition to understanding the mechanisms of resistance is required.

2. Breeding for increased resistance/tolerance to diseases and reduced aflatoxin levels is being practiced but the amount of resistance achievable may be limited due to complicated genetics and/or linkage to undesirable agronomic traits. Molecular markers can be employed to speed up the incorporation of chromosomal regions that have a quantitative effect on resistance (quantitative trait loci).
3. Research into exploring new ways of applying biotechnology is needed to deal with viral diseases like bud necrosis and stem necrosis. PBNV infects several crops, ornamental and weeds, making its control. Resistance to PBNV is scarce in the germplasm. Field resistance to bud necrosis is due to the vector resistance. An effort to develop transgenic resistance to manage these viral diseases is required. New paths might include the engineering of resistance to tospoviruses by expressing the tospovirus glycoproteins in transgenic plants to block virus acquisition by thrips, by expressing truncated or modified forms of movement protein(s) of heterologous viruses, or by expressing tospovirus-specific antibody genes. It is imperative that a combination of conventional and biotechnological methods be deployed to minimize losses caused by tospoviruses. This combination includes the cultivation of virus resistant plants developed through conventional breeding or transgenic technology, use of appropriate cultural practices, and vector management.
4. Increased biocontrol research: It has been established that the biocontrol agents possess differing modes of action against plant pathogens and it is not necessary that all strains of biocontrol agents possess all these modes of actions for effective biocontrol ability. Attempt to select broad-spectrum, fungicide tolerant and thermo-tolerant biocontrol agents that can be a useful component of IDM is required. Research also needs to be carried out to answer the questions like, how are pathogens and their antagonists distributed in the environment, under what conditions do biocontrol agents exert their suppressive capacities, how do native and introduced populations respond to different management practices, what determines successful colonization and expression of biocontrol traits, what are the components and dynamics of plant host defence induction?

5. Increased aflatoxin research: There is a need to identify stable sources of resistance to seed colonization by *A. flavus.* The identified sources could be profitably exploited for incorporation of resistance to multiple stresses in general and infection to *A. flavus* in particular. Attempts could be made to produce transgenic with Glutathione-S transferase (GSH) genes in groundnut. This could be another possible approach to manage aflatoxin contamination. The lipoxygenase enzymes (LOXs), recently characterized and cloned, are suspected of playing an important role in the *Aspergillus* seed interaction. The studies demonstrated that *Aspergillus* infections induce seed lipoxygenase expression leading to generation of bioactive oxylipins. The study of LOXs expression might provide some support to screen groundnut genotypes against *A. flavus*.

   Distribution of aflatoxin in groundnut is highly positively skewed. Given skewed distribution of aflatoxin, particularly in whole kernels, it is extremely difficult to collect sample which accurately represent the mean lot concentration. As a result, sampling step is the largest source of variation. Development of simple, efficient, cost-effective sampling and analytical methods suitable for screening and segregation of contaminated lots of commodities early in the marketing chain and for control during processing are required.

6. There has been only limited exploitation of wild species in secondary and tertiary gene pools due to cross incompatibility with the cultigens. These genepools include species that are sources of multiple resistance to important biotic and abiotic stresses, therefore of significant value. Recent advances in plant biotechnology may provide new tools to exploit the genes locked up in these gene pools. Where amenable, molecular marker facilitated can be effectively used for transfer of genes of interest breaking undesirable linkages or linkage drag. Molecular markers may be used to map resistance genes in crosses between wild species or accessions of the same species in the secondary and tertiary genepools and once resistance genes are located, they can be transformed into cultivated germplasm.

7. Development of good agricultural practices during pre- and post-harvest stages including appropriate drying techniques and storage of groundnut is required. Further, there is a need to develop groundnut harvesters that can make the harvested plants upside down in field while harvesting which will minimize probability of aflatoxin contamination of groundnut kernels in the field.

8. Development of novel alternative fungicides that triggers defence

mechanism of host and the plant derived fungicides to manage foliar diseases of groundnut may be emphasized.

REFERENCES

Adams, D.B. and Kuhn, C.W. (1977). Seed transmission of peanut mottle virus in peanut. *Phytopathology* 67: 1126-1129.

Adiver, S.S. and Anahosur, K.H. (1995). Efficacy of some triazole fungicides against late leaf spot of groundnut and their subsequent effects on *Sclerotium rolfsii. Indian Phytopath.* 48(6): 459-462.

Akram, M., Jain, R.K., Chaudhary, V., Ahlawat,Y.S. and Paul Khurana, S.M. (2004). Comparison of *Groundnut Bud Necrosis Virus* isolates based on movement protein (NSm) gene sequences. *Ann. Appl. Biol.* 145: 285-289.

Ashtaputre, S.A., Srikant Kulkarni, Anahosur, K.H. and Kulkarni, S. (1994). Influence of sowing dates on the incidence of late leaf spot of groundnut *(Arachis hypogaea* L.). *Karnataka J. Agric. Sci.* 7: 178-180.

Balasubramanian, R. (1979). A new type of alternariosis in *Arachis hypogea* L. *Curr. Sci*. 48: 76-77.

Barnes, J.S., Csinos, A.S. and Hook, J.E. (1990). Effects of fungicides, cultivars, irrigation and environment on *Rhizoctonia* limb rot of peanut. *Plant Dis.* 74: 671-675.

Basu, M.S. (2001). Aflatoxin Management in Groundnut. National Research Centre for Groundnut (ICAR), Junagadh, India. p. 15.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011a). NRCGCS 77 (IC0582472; INGR10029), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis disease), Stem rot, Late leaf spot, Early leaf spot, Rust and Alternaria leaf blight. *Indian J. Plant Genet. Resour.* 24(1): 110.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011b). NRCGCS 85 (IC0582473; INGR10030), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis disease), Stem rot, Late leaf spot, Early leaf spot, Rust and Alternaria leaf blight. *Indian J. Plant Genet. Resour.* 24(1): 110.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011c). NRCGCS 86 (IC0582474; INGR10031), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis disease), Stem rot, Late leaf spot, Early leaf spot, Rust and Alternaria Leaf blight. *Indian J. Plant Genet. Resour.* 24(1): 111

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011d). NRCGCS 21 (IC0583387; INGR10036), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis disease), Stem rot, tolerant to Late leaf spot, Early leaf spot. *Indian J. Plant Genet. Resour.* 24(1): 112.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011e). NRCGCS 83 (IC0583388; INGR10037), Groundnut (*Arachis*

hypogaea) germplasm, a source of resistance to PBND (Peanut bud necrosis disease), Stem rot, tolerant to Late leaf spot, Alternaria Leaf blight. *Indian J. Plant Genet. Resour.* 24(1): 112.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011f). NRCGCS 124 (IC0583389; INGR10038), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis diseases), Stem Rot, tolerant to Late Leaf Spot, Alternaria Leaf Blight. *Indian J. Plant Genet. Resour.* 24(1): 113.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011g). NRCGCS 180 (IC0583390; INGR10039), Groundnut (*Arachis hypogaea*) germplasm, a source of resistance to PBND (Peanut bud necrosis diseases), Stem Rot, tolerant to Late Leaf Spot, Alternaria Leaf Blight. *Indian J. Plant Genet. Resour.* 24(1): 113.

Bera, S.K., Kumar, V., Sunkad, G., Rathnakumar, A.L. and Radhakrsihnan, T. (2011h). NRCGCS 222 (IC0583391; INGR10040), Groundnut (*Arachis hypogaea*) germplasm, a source resistance to PBND (Peanut bud necrosis diseases), Stem Rot, tolerant to Late leaf spot, Early leaf spot and Alternaria leaf blight. *Indian J. Plant Genet. Resour.* 24(1): 114.

Bhat, R.V. and Rao, R.N. (1990). Practical guide for prevention and control of aflatoxins in groundnuts. National Institute of Nutrition, Indian Council of Medical Research, Hyderabad, India, p. 16.

Bhatnagar, D., Cleveland, T.E. and Ehrlich, K.C. (2003). Molecular genetic analysis and regulation of aflatoxin biosynthesis. *Appl. Environ. Biotechnol.* 61: 83-93.

Biswas, K.K., Chitreshwar, Sen and Sen, C. (2000). Management of stem rot of groundnut caused by *Sclerotium rolfsii* through *Trichoderma harzianum. Indian Phytopath*. 53(3): 290-295.

Chandrasekhar, V., Narayanaswami, R. and Ramabadran, R. (1994). Effect of foliar spray of potash and neem seed extract on the tikka leaf spot of groundnut. *Indian Phytopath.* 47(2): 188-189.

Chohan, J.S. (1974). Recent Advances in diseases of groundnut in India. In: *Current Trends in Plant Pathology*, Uttar Pradesh, India, Lucknow University Press, pp. 171-178.

Cole, R.J., Sanders, T.H., Dorner, J.W. and Blankenship, P.D. (1989). Environmental conditions required to induce pre-harvest aflatoxin contamination of groundnuts: summary of six years' research. In: McDonald, D., Mehan, V.K. (Eds.), Aflatoxin Contamination of Groundnut. Proceedings of the International Workshop, 9th Oct 1987, ICRISAT Center, India, pp. 279-287.

Culbreath, A.K. and Brenneman, T.B. (1992). Combining Centre Pivot irrigation applications of clorothalonil with moderately resistant cultivar for control of late leaf spot in peanut. *Plant Dis.* 76: 29-32.

Das, N.D., Srivastava, N.N. and Rao, B.V.R. (1997). Comparative efficacy of spray schedule against leaf spot/tikka diseases of groundnut. *Ann. Plant Prot. Sci.* 5: 103-107.

Dasgupta, S., Raj, S.K. and Das, S. (1998). Management of collar rot disease of groundnut by seed treatment with growth regulators-an alternative approach. *International Arachis Newsletter* 18: 21-22.

Demski, J.M. and Khun, C.W. (1983). Peanut mottle In: Peanut Disease Compendium Eds. Porter, D.M., Smith, D.H. and Rodriguez-Kabana, R. St. Paul, Minesota. The U.S. American Phytopathological Society, pp. 45-46.

Desai, S. and Bagwan, N.B. (2002). Mass multiplication and formulation of fungal biocontrol agents against late leaf spot pathogen of groundnut in the Saurashtra region of Gujarat, Asian Congress of Mycology and Plant Pathology, Mysore, (Karnataka), October 1-4, 2002: ISMPP.

Desai, S. and Basu, M.S. (2002). Aflatoxin contamination in groundnut-a potential non-tariff trade barrier and food safety. In: Quarantine, SPS and WTO. Proceedings of the Asian Congress of Mycology and Plant Pathology, Mysore, India, 1-4 October 2002.

Desai, S., Bagwan, N.B. and Yeole, R.D. (2003). Effect of mustard cake extract on *Sclerotium rolfsii* causing stem rot of groundnut and *Trichoderma*, a common biocontrol agent at National Seminar on "*Stress Management in Oilseed for Attaining Self-Reliance in Vegetable Oils*" January 28-30, 2003 :ISOR.

Desai, S., Yeole, R.D., Kelaiya, D.S. and Bagwan, N.B. (2002). Evaluation of species of Bacteria for the management of aflatoxigenic strain of *Aspergillus flavus* and promotion of growth in groundnut. Paper presented at Zonal meet (Western Zone) of Indian Phytopathological Society held at Central Institute for Cotton Research, Nagpur, October 29-30, 2002.

Durairaj, P. and Mohan, R. (1978). Evaluation of fungicide for the control of groundnut rust. *Madras Agric. J.* 65: 692.

Ferguson, L.M. and Shew, B.B. (2001). Wheat straw mulch and its impact on three soil borne pathogens of peanut in microplots. *Plant Dis.* 85: 661-667.

Ganpathy, T. and Narayanasamy, P. (1990). Effect of plant products on the incidence of major diseases of groundnut. *International Arachis Newsletter* 7: 20-21.

Ghanekar, A.M. (1980). Groundnut Virus Research at ICRISAT. Proceedings of the International Workshop on groundnuts, 13-17 October 1980. Eds. R. W. Gibbons and J.V. Martin, International Crops Research Institute for the Semi- Arid Tropics, Patancheru, India, pp. 211-216.

Ghewande, M.P. (1983). Effect of cultural practices on the disease (bud necrosis, collar rot, stem rot) incidence and yield of groundnut. *Indian Bot. Rep.* 2: 176-177.

Ghewande, M.P. (1985) Seed and seedling diseases of groundnut deserve attention for better productivity. *Seeds and Farms* 11: 9-12&19.

Ghewande, M.P. (1987). Virus diseases of groundnut and their management. In: Symposium on Diseases of Oilseed and Pulse Crops and their Control., Eds. S.C. Vyas and V.N. Shroff, J.N.K.V.V. Indore, (M.P.) pp. 62-67.

Ghewande, M.P. (1989a). Management of foliar diseases of groundnut (*Arachis hypogea*) using plant extracts. *Indian J. Agric. Sci.* 59: 133-134.

Ghewande, M.P. (1989b). Biological control of late leaf spot (*Phaeoisariopsis personata* Berk. Curt.) V. Arx. of groundnut. *Indian J. Agric. Sci.* 59: 189-190.

Ghewande, M.P. (1990a). Diseases of groundnut and their management. *J. Oilseeds Res.* 7(1): 78-97.

Ghewande, M.P. (1990b). Biological control of groundnut (*Arachis hypogaea* L.) rust (*Puccinia arachidis* Speg.) in India. *Trop. Pest Manage.* 36 (1): 17-20.

Ghewande, M.P. (1997). Aflatoxin contamination of groundnut and its management in India. In: Mehan, V.K., Gowda, C.L.L. (Eds.), Aflatoxin Contamination Problems in Groundnut in Asia. Proceedings of the First Asia Working Group Meeting, 27-29 May, 1996, ICRISAT, Patancheru, Andhra Pradesh, India, pp. 27-31.

Ghewande, M.P., Desai, S. and Basu, M.S. (2002). Diagnosis and management of major diseases of groundnut, *NRCG Technical Bulletin,* 3-12 pp.

Ghewande, M.P., Desai, S., Prem Narayan and Ingle, A.P. (1993). Integrated management of foliar diseases of groundnut (*Arachis hypogaea* L.) in India. *Int. J. Pest Manage.* 39(4): 375-378

Ghewande, M.P., Desai, S., Prem Narayan and Kamble, S.D. (1992). Some sources of resistance to early leaf spot of groundnut (*Arachis hypogaea* L.) in India. *Trop. Agric.* (Trinidad) 69: 284-286.

Ghewande, M.P., Pandey, R.N., Shukla, A.K. and Misra, D.P. (1982). A new leaf blight disease of groundnut caused by *Alternaria tenuissima* (Kunze ex Pers.) wilts. *Curr. Sci.* 51: 845-846.

Ghewande, M.P., Savaliya, S.D., Hingrajia, H.M. and Padavi, R.D. (2003). Management of stem rot (*Sclerotium rolfsii* Sacc.) through organic soil amendments in groundnut. In: Proceedings of the National Symposium on *Recent Advances in Management of Plant Diseases, Technology Development and Applications*, held at Pune, India, 20-21 December, 2003, pp. 9-10.

Ghewande, M.P., Shukla, A.K. Pandey, R.N. and Mishra, D.P. (1983). Losses in groundnut yields due to leaf spots and rust at different intensity levels. *Indian J. Mycol. Plant Pathol*. 13 (1): 123-127.

Ghuge, S.S., Mayee, C.D. and Godbole, G.M. (1981). Assessment of losses in peanut due to rust and tikka leaf spots. *Indian Phytopath.* 34: 179-182.

Giri, G.S. and Murugesan, K. (1996). A first report of *Alternaria longipes* on groundnut from Tamil Nadu, India. *International Arachis Newsletter* 6: 35.

Gorbet, D.W., Knauft, D.A. and Shokes, F.M. (1990). Response of peanut genotypes with differential levels of leaf spot resistance to fungicide treatment. *Crop Sci.* 30: 529-533.

Govindasamy, V. and Balasubramaniyam, R. (1989). Biological control of groundnut rust, *Puccinia arachidis*, by *Trichoderma harzianum. Z. Pflanzenkr Pflanzenpathol Pflanzenschutz* 96: 337-345.

Govindasamy, V., Gunaratna, K.R. and Balasubramaniyam, R. (1998). Properties of extra cellular chitinase from *Myrothecium verrucaria,* an antagonist to the groundnut rust *Puccinia arachidis. Can. J. Pathol.* 20: 62-68.

Grewal, P.S., Chhabara, H.K. and Kaul, V.K. (1986). Screening of groundnut

germplasm against root knot nematode *Meloidogyne arenaria. Indian J. Nematol.* 17: 151-152.

Hill, R.A., Wilson, D.M., McMillan, W.W., Widstrom, N.W., Cole, R.J., Sanders, T.H. and Blankenship, P.D. (1985). Ecology of the *Aspergillus flavus* group and aflatoxin formation in maize and groundnut. In: Lacey, J. (Ed.), Trichothecenes and Other Mycotoxins, John Wiley & Sons Ltd., UK, pp. 79-95.

Horn, B.W., Greene, R.L. and Dorner, J.W. (1995). Effect of corn and peanut cultivation on soil populations of *Aspergillus flavus* and *A. parasiticus* in southwestern Georgia. *Appl. Environ. Microbiol.* 61: 2472-2475.

Jadeja, K.B., Nandolia, D.M., Dhruj, I.U. and Khandar, R.R. (1999). Efficacy of four triazole fungicides in the control of leaf spots and rust of groundnut. *Indian Phytopath.* 52(4): 421-422.

Johnson, M. Rao, M.M. and Meenakumari, K.V.S. (1998). Chemical control of groundnut late leaf spot in Anantpur district of Andhra Pradesh. *Indian Phytopath.* 51: 382-384.

Karthikeyan, A. (1996). Effect of organic amendments, antagonist *Trichoderma viride* and fungicides on seed and collar rot of groundnut. *Plant Dis. Res.* 11(1): 72-74.

Kendre, M.S., Patange, N.R., Neharkar, P.S. and Telang, S.M. (2000). Occurrence of *Thrips palmi*, a vector of bud necrosis disease of groundnut in Marathawada region. *J. Soil Crops* 10(2): 226-230

Kishore, G.K., Pande, S. and Podile, A.R. (2005). Biological control of collar rot disease with broad-spectrum antifungal bacteria associated with groundnut. *Can. J. Microbiol.* 51(2): 123-132

Kishore, G.K., Pande, S., Naryana, R.J. and Podile, A.R. (2003). Evaluation of chitinolytic strains of *Serratia marcescens* and *Bacillus circulans* for biological control of late leaf spot of groundnut. *ISOR National Seminar: Stress Management in Oilseeds*, Jan. 28-30, 2003. pp. 19-20.

Kodmelwar, R.W. and Ingle, A.Y. (1989). Effect of sowing dates, spacing and meteorological factors on the development of tikka and rust of groundnut. *Indian Phytopath.* 42: 274.

Kolte, S.J. (1984). Diseases of annual edible oilseed crops. Peanut diseases Vol.1 Florida, CRC Press Incorporated, USA, pp. 29.

Kuhn, C.W. and Demski, J.W. (1975). The relationship of peanut mottle virus to peanut production. Georgia Agriculture Experiment Station Research Report No. 213. pp.19.

Kulkarni, R.L. (1974). Three fungi from groundnut leaf surface. *Curr. Sci*. 43: 561-562.

Kulkarni, S.A., Srikant Kulkarni and Kulkarni, S. (1994). Biological control of *Sclerotium rolfsii* Sacc. - a casual agent of stem rot of groundnut. *Karnataka J. Agric. Sci.* 7: 365-367.

Kulkarni, S.A., Srikant Kulkarni and Kulkarni, S. (1995). Effect of organic amendments and green manuring on the survival of collar rot fungus of

groundnut. *Current Research University of Agricultural Sciences*, *Bangalore*, 24: 135-136.

Kumar, K.V.K., Desai, S., Rao, V.P., Nur, H.A., Srilakshmi, P. and Thakur, R.P. (2002). Evaluation of an integrated management package to reduce pre-harvest seed infection by *Aspergillus flavus* in groundnut. *International Arachis Newsletter* 22: 42-44.

Kumar, V., Bagwan, N.B. and Rathnakumar, A.L. (2010). Effect of root exudates of crops on *Sclerotium rolfsii* causing stem rot disease of groundnut. *In:* Proceedings of the 32nd Annual Conference & Symposium of Indian Society of Mycology and Plant Pathology on "Innovations in Plant Pathology Research and Human Resource Development", November 24-26, 2010 held at Junagadh (Gujarat) India, pp. 52-53 (published in *J. Mycol Plant Pathol*. 40(4): 617-618.

Kumar, V., Bagwan, N.B., and Singh, D. (2009). On-farm evaluation of cultural practices for management of aflatoxins in groundnut. *J. Mycol Plant Pathol*. 39(2): 271-274.

Kumar, V., Bagwan, N.B., Koradia, V.G. and Padavi, R.D. (2010b). Colour sorting - an effective tool to remove aflatoxin contaminated kernels in groundnut. *Indian Phytopath.* 63(4): 449-451

Kumar, V., Bagwan, N.B., Vyas, U.M. and Singh, D. (2008). Dynamics of soil population of *Aspergillus flavus* Link and aflatoxin contamination in groundnut based production system in Gujarat. *Indian Phytopath.* 61(3): 343-347.

Kumar, V., Basu, M.S. and Rajendran, T.P. (2008). Mycotoxin research and mycoflora in some commercially important agricultural commodities. *Crop Prot.* 27: 891-905.

Kumar, V., Ghewande, M.P. and Basu, M.S. (2005). Safeguard Groundnut from Aflatoxin Contamination. National Research Centre for groundnut (ICAR), Junagadh, India, p. 15.

Kumar, V., Ghewande, M.P., Girdhar, I.K, Padavi, R.D. and Bhalodia, P.K. (2010a). Effect of salinity stress on foliar fungal diseases of groundnut. *Indian Phytopath.* 63(3): 273-277.

Kumar, V., Lukose, C., Bagwan, N.B., Koradia, V.G. and Padavi, R.D. (2009). *Alternaria* leaf blight disease of groundnut spreads in Saurastra region of Gujarat *In:* Proceedings of the 31st Annual Conference & Symposium of Indian Society of Mycology and Plant Pathology on "Microbial Wealth-Plant Health", October 23-25, 2009 at NBU, Siliguri, India, pp. 15. (Published in 2009 in *J. Mycol. Plant Pathol*. 39(3): 549.

Kumar, V., Lukose, C., Bagwan, N.B., Koradia, V.G. and Padavi, R.D. (2012). Occurrence of Alternaria leaf bight of groundnut in Gujarat and reaction of some genotypes against the disease. *Indian Phytopath.* 65(1): 25-30.

Kumar, V., Rathnakumar, A.L. and Bagwan, N.B. (2012). Effect of crop residues and root exudates on mycelial growth, sclerotial formation, and *Sclerotium rolfsii*-induced stem rot disease of groundnut. *Indian Phytopath.* 65(3): 238-243.

Lin, K.H. and Cheng, Z. (1980). Control of groundnut leaf rust with a mixture of dixiu-na and colloidal sulphur. *J. South China Agric. Coll.* 1: 73-85.

Lokesh, B., Rashmi, P.R., Amruta, B.S., Srisathiyanarayanan, D., Murthy, M.R.N. and Savithri, H.S. (2010). NSs Encoded by *Groundnut Bud Necrosis Virus* is a bifunctional enzyme. *PLoS ONE* 5: e9757. doi:10.1371/journal.pone.0009757.

Lokhande, N.M., Lanjewar, R.D. and Newaskar, V.B. (1998). Effect of different fungicides and neem products for control of leaf spot of groundnut. *J. Soil Crops* 8: 44-46.

Mahapatra, T.K. and Tewari, S.N. (1994). *Ocimum sanctum* L. leaf extracts toxicity against collar rot (*Aspergillus niger*) and yellow root (*A. flavus*) diseases of groundnut. *Allelopathy J.* 1: 114.

Mathivanan, N. and Murugesan, K. (2000). *Fusarium chlamydosporum*, a potent biocontrol agent to groundnut rust, *Puccinia arachidis*. *Z. Pflanzenkr Pflanzenpathol Pflanzenschutz* 107: 225-234.

Mayee, C.D. and Datar, V.V. (1988). Disease of groundnut in the tropics. *Rev. Trop. Plant Pathol.* 5: 169-198.

Mayee, C.D., Patil, M.A., Godbole, G.M., Kide, D.S. and Patil, F.S. (1979). Fungicidal control of groundnut rust. *Pesticides* 13: 13-14.

Mc Donald, D., Subrahmaniyam, P., Gibbons, R.W. and Smith, S.D.H. (1985). Early and late leaf spots of groundnut. *Information Bulletin No.21*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India.

Moraes, S.A. and Godoy (1985). Evaluation of resistance to *Cercosporidium personatum* in *Arachis hypogaea* genotypes. *Summa Phytopathol.* 11: 140-151.

Nagarju, P. and Urs, S.D. (1998). Comparative efficiency of fungicides and bioagents against *Aspergillus niger,* a casual agent of collar rot of groundnut. *Current Research, University of Agricultural Sciences Bangalore* 27: 137-139.

Naidu, P.H. and Chandrika, V. (1997). Effect of dates of sowing on the occurrence of tikka late leaf spot and rust on groundnut in southern zone of Andhra Pradesh. *J. Oilseeds Res.* 14(2): 238-240.

Naidu, P.H. and Rao, A.S. (1997). Relative efficacy of number of sprays of fungicides on the control of late leaf spot in groundnut. *Indian J. Plant Prot.* 25: 45-47.

Naidu, P.H., Mosas, G.J. and Sitaramaiah, K. (2000). Control of groundnut Kalahasti malady (*Tylenchorhynchus brevilineatus*) through organic and inorganic soil amendments. *J. Mycol. Plant Pathol.* 30(2): 180-183.

Narain, A., Sahu, K.C. and Swin, N.C. (1981). Comparative efficacy of selected fungicides and a plant extract on tikka disease of groundnut. *Pesticides* 15: 27-28.

Narain, U., Chauhan, L.S. and Swarup, J. (1987). Occurrence of two foliar diseases of groundnut - new to Uttar Pradesh. *Farm Sci. J.* 2: 202-203.

Nolt, B.L. and Reddy, D.V.R. (1984). Peanut Clump. In: *Compendium of Peanut Diseases* Eds. Porter, D.M., Smith, D.H. and Rodriguez-Kabana, R. American Phytopathological Society, pp. 73.

O'Brien, K., Moss, E., Judah, D. and Neal, G. (1983). Metabolic basis of the species difference to aflatoxin B1 induced hepatoxicity. *Biochem. Biophys. Res. Commun.* 114: 813-821.

Ozias, Akins, P., Schnall, J.A., Anderson, W.F., Singsit, C., Clemente, T.E., Adang, M. J. and Wessinger, A.K. (1993). Regeneration of transgenic peanut plants from stably transformed embryonic callus. *Plant Sci.* 93: 185-194.

Pande, S., Rao, J.N., Upadhyaya, H.D. and Lenne, J.M. (2001). Farmers' participatory integrated management of foliar diseases of groundnut. *Int. J. Pest Manage.* 47(2): 121-126.

Patil, P.V. and Hiremath, P.C. (1989). A new leaf blight disease of groundnut caused by *Alternaria tenuissima* (Kunze. Fr) Wiltshire in Karnataka. *Curr. Sci.* 58: 151.

Patil, R.P., Jagadeesh, K.S. and Kulkarni, J.H. (1998). Isolation of fluorescent pseudomonds associated with roots of different plants and their *in vitro* antagonism against groundnut collar rot pathogen *Sclerotium rolfsii* Sacc. *Karnataka J. Agric. Sci.* 11: 45-4.

Payne, G.A. and Brown, M.P. (1998). Genetics and physiology of aflatoxin biosynthesis. *Ann. Rev. Phytopathol.* 36: 329-362.

Pixley, K.V., Boote, K.J., Shokes, F.M. and Gorbert, D.W. (1990). Growth and partitioning characteristics of four peanut genotypes differing in resistance to late leaf spot. *Crop Sci.* 30: 796-804.

Podile, A.R., and Prakash, A.P. (1996). Lysis and biological control of *Aspergillus niger* by *Bacillus subtilis* AF1. *Can. J. Microbiol.* 42: 533-538.

Prabhu, K.S. and Urs, S.D. (1998). Efficiency of bioagents for management of collar rot of groundnut caused by *Aspergillus niger. Current Research University of Agricultural Sciences, Bangalore* 27: 114-115.

Prasada Rao, R.D.V.J., Reddy, A.S., Reddy, S.V., Thirumala Devi, K., Chandar Rao, S., Manoj Kumar V., Subramniam, K., Yellamanda Reddy, T., Nigam, S.N. and Reddy, D.V.R (2003b). The host range of *Tobacco streak virus* in India and transmission by thrips. *Ann. Appl. Biol.* 142: 365-368.

Prasada Rao, R.D.V.J., Reddy, D.V.R., Nigam, S.N., Reddy, A.S., Waliyar, F., Yellamanda Reddy, T., Subramanyam, K., John Sudheer, M., Naik, K.S.S. Bandyopadhyay, A., Desai, S., Ghewande, M.P., Basu, M.S. and Somasekhar (2003a). Peanut Stem Necrosis: A New Disease of Groundnut in India. Information Bulletin No. 67. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 12 pp.

Rago, A., March, G.J. and Marinelli, A. (1997). Effect of plant residues on Sclerotia production by *Sclerotium rolfsii. Fitopatologia* 32:121-125.

Rahman, M.A., Ahmed, H.U. and Alam, K.B. (1986). Studies on the efficacy of fungicides and the date of commencing of spray in controlling tikka and rust of groundnut. *Bangladesh J. Pathol.* 2: 61.

Rakh, R.R., Raut, L.S., Dalvi, S.M. and Manwar, A.V. (2011). Biological control of S*clerotium rolfsii*, causing stem rot of groundnut by *Pseudomonas cf. monteilii 9 Recent Res. Sci. Technol.* 3(3): 26-34.

Ramsdell, H.S. and Eaton, D.L. (1990). Species susceptibility to aflatoxin B1 carcinogenesis: Comparative kinetics of microsomal biotransformation. *Cancer Res.* 50: 615-620.

Ratna, A.S., Rao, A.S., Nolt, B.L., Reddy, D.V.R., Vijayalakshmi, M. and Mc Donald, D. (1991). Studies on the transmission of Indian peanut clump virus disease by *Polymyxa graminis*. *Ann. Appl. Biol.* 118: 71-78.

Rattan, G.S. and Kang, M.S. (1984). Efficiency of different systemic and non-systemic fungicides against 'tikka' disease of groundnut and their effects on host physiology. *Pesticides* 18: 30-33.

Reddy, A.S., Prasada Rao, R.D.V.J., Thirumala Devi, K. Reddy, S.V., Mayo, M.A., Roberts, I., Satyanarayana, T., Subramaniam, K. and Reddy, D.V.R. (2002). Occurrence of Tobacco streak virus on peanut (*Arachis hypogaea* L.) in India. *Plant Dis*. 86: 173-178.

Reddy, C.D.R., Srinivas, T. and Reddy P.N. (1997). Evaluation of advanced groundnut lines for resistance to early and late leaf spots. *International Arachis Newsletter* 17: 13-15.

Reddy, D.V.R., Amin, P.W., Mc Donald, D. and Ghanekar, A.M. (1983). Epidemiology and control of groundnut bud necrosis and other diseases of legume crops in India caused by tomato spotted wilt virus. In: Plant Diseases Epidemiology Eds. R.T. Plumb and J.M. Tresh, J.K., Blackwell, Oxford, pp. 93-102.

Reddy, D.V.R., Iizuka, N., Ghanekar, A.M., Murthy, V.K., Kuhn, C.W., Gibbons, R.W. and Chohan, J.S. (1978). The occurrence of peanut mottle virus in India. *Pl. Dis. Reptr.* 62: 978-982.

Reddy, D.V.R., Wightman, J.A., Bashear, R.J., Highland, B., Black, M., Sreenivasalu, P., Dwivedi, S.L., Demski, J.W., Mc Donald, D., Smith, Jr. J.W. and Smith, D.J. (1991). Bud necrosis: a disease of groundnut caused by tomato spotted wilt virus. Information Bulletin no. 31.International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India.

Reddy, M., Reddy, D.V.R. and Appa Rao, A. (1968). A new record of virus disease on peanut. *Plant Dis. Rep.* 52: 494-495.

Reddy, P.S. (1988). Genetics, breeding and varieties. In: *Groundnut*, Ed. P.S. Reddy, pp. 508-525.

Reis, R.F., de Goes, A., Mondal, S.N., Shilts, T., Brentu, F.C. and Timmer, L.W. (2006). Effect of lesion age, humidity, and fungicide application on sporulation of *Alternaria alternata*, the cause of brown spot of tangerine. *Plant Dis.* 90: 1051-1054.

Rodriguez-Kabana, R. and Morgan-Jones, G. (1987). Novel rotations and organic materials show promise for management of nematode. Alabama Agricultural Experiment Station. Highlights of Agricultural Research, 34: 13.

Rodriguez-Kabana, R., Roberson, D.G., Wells, L., Weaver, C.F. and King, P.S. (1991). Cotton as a rotation crop for the management of *Meloidogyne arenaria* and *Sclerotium rolfsii* in peanut. Supplement of *J. Nematol.* 23: 652-657.

Rohini, V.K. and Rao K.S. (2001). Transformation of peanut (*Arachis hypogea* L.) with tobacco chitinase gene: variable response of transformants to leaf spot disease. *Plant Sci.* 160(5): 889-898.

Roulin, S. and Buchala, A.J. (1995). The induction 1, 3-ß-glucanases and other enzymes in groundnut leaves infected with *Cercospora arachidicola. Physiol. Mol. Plant Pathol.* 46: 471-489.

Sailaja, P.R., Podile, A.R. and Reddanna, P. (1998). Biocontrol strain of *Bacillus subtilis* AF1 rapidly induces lipoxygenase in groundnut (*Arachis hypogaea* L.) compared to crown rot pathogen *Aspergillus niger. Eur. J. Plant Pathol.* 104: 125-132.

Sakthivel, N., Sivamani, Anuratha, C.S., Savithiry, S., Gnanamanickam, S.S. and Mahadevar, A. (1988). Beneficial bacteria for plant disease management. Proceeding of the National Symposium on Phytobacteriology held at the University of Madras, Madras, India during March, 14-15, 1986, 213-220.

Sanders, T.H., Cole, R.J., Blankenship, P.D. and Dorner, J.W. (1993). Aflatoxin contamination of peanuts from plants drought stressed in pod or root zones. *Pean. Sci.* 20: 5-8.

Sanders, T.H., Cole, R.J., Blankenship, P.D. and Hill, R.A. (1985). Relation of environmental stress duration to *Aspergillus flavus* invasion and aflatoxin production in pre-harvest peanuts. *Pean. Sci.* 12: 90-93.

Sathiyabama, M. and Balasubrahmanium, R. (1998). Chitosan induces resistance components in *Arachis hypogaea* against leaf rust caused by *Puccinia arachidis* Speg. *Crop Prot.* 17(4): 307-313.

Sathiyanarayanmurthy, G.V., Ramasubbiah, K., Rama Subba Rao, K. and Krishnamurthy, M.M. (1988). Efficacy of certain synthetic pyrithroids and in combination against thrips and leaf miner of groundnut. Journal of Agricultural Research, Andhra Pradesh Agricultural University, 16: 16-19.

Satyanarayana, T., Mitchell, S.E., Reddy, D.V., Brown, S. and Kresovich, S. (1996a). Peanut bud necrosis tospovirus S RNA: complete nucleotide sequence, genome organization and homology to other tospovirus. *Arch. Virol.* 141: 85-98.

Satyanarayana, T., Mitchell, S.E., Reddy, D.V., Brown, S., Kresovich, S. and Jarret, R. (1996b). The complete nucleotide sequence and genome organization of the M RNA segment of peanut bud necrosis tospovirus and comparison with other tospoviruses. *J. Gen. Virol.* 77: 2347-2352.

Schroder, J., Schanz, S., Tropfg, S., Karcher, B. and Schroder, G. (1993). Phytoalexin biosynthesis: stilbene synthase and co-action of a reductase with chalcone synthase. In: *Mechanism of Plant Defense Responses* (Fritig, B., [editor Legrand, M.). Kluwer Academic, The Netherlands, pp. 257-267.

Sekhon, I.S., and Dhillon, A.S. (1981). Studies on chemical control of 'tikka' disease of groundnut. *Pesticides* 15: 19-21.

Seshakiran, K. and Adiver, S.S. (2003). Efficacy of plant extracts against *Sclerotium rolfsii*- the incitant of stem rot of groundnut (*Arachis hypogea* L). *ISOR National Seminar: Stress Management in Oilseeds*, Jan. 28-30, 2003. pp.13-15.

Sharma, S.B. and Mc Donald, D. (1990). Global status of nematode problem of groundnut, pigeon pea, chickpea, sorghum and pearl millet and suggestion for future works. *Crop Prot.* 9: 453-458.

Sheela J., Sivaprakasam, K. and Seetharaman, K. (1998). Effect of soil application of *Pseudomonas fluorescens* using different carriers on groundnut collar rot disease. *Madras Agric. Univ. J.* 85: 191-192.

Sheela, J. and Packiaraj, D. (2000). Management of collar rot by *Pseudomonas fluorescens*. *International Arachis Newsletter* 20: 50-51.

Shukla, S., Kalyani, G., Kulkarni, N., Waliyar, F. and Nigam, S.N. (2005). Mechanism of transmission of *Tobacco streak virus* by *Scirtothrips dorsalis, Frankliniella schultzei* and *Megalurothrips usitatus* in groundnut, *Arachis hypogea* L. *J. Oilseeds Res.* 22: 215-217.

Siddaramaiah, A.L., Desai, S.A. and Hegde, R.K. (1981). Effect of few herbicides on crown rot and afla- root disease of groundnut. *Mysore J. Agric. Sci.* 15: 44-47.

Singh, S.D. and Naik, S.M.P. (1977). Field evaluation of modern fungicides for the control of tikka disease of groundnut. *Pesticides* 11: 49-50.

Sivan, A. and Harman, G.E. (1991). Improved rhizosphere competence in a protoplast fusion progeny of *Trichoderma harzianum. J. Gen. Microbiol.* 137: 23-29.

Sivan, A. Stasz, T.E., Hemmat, M., Hayes, C.K. and Harman, G.E. (1992). Transformation of *Trichoderma* spp. with plasmids conferring hygromycin B resistance. *Mycologia* 84: 687-694.

Sobti, A.K., Sharma, O.P. and Bhargava, A.K. (1995). A comparative study of fungicidal compounds and plant extracts against three pathogens of *Arachis hypogea*. *Indian Phytopath.* 48: 191-193.

Srinivas, T., Rao, M.S., Reddy, P.S. and Reddy, P.N. (1997). Integrated management of leaf spot of groundnut (*Arachis hypogaea* L.) with botanicals and chemicals. *Z. Pflanzenkr Pflanzenpathol Pflanzenschutz* 104: 528-530.

Stalker, H.T. (1991). Utilizing wild species for crop improvement. In: Scientific management of germplasm: characterization, evaluation and enhancement. *IBPGR training courses: lecture series* 2: 139-161.

Stasz, T.E. and Harman, G.E. (1990). Nonparental progeny resulting from protoplast fusion in *Trichoderma* in the absence of parasexuality. *Exp. Mycol.* 14: 145-159.

Stasz, T.E., Harman, G.E., and Gullino, M.L. (1989). Limited vegetative compatibility following intra- and inter- specific protoplast fusion in *Trichoderma. Exp. Mycol.* 13: 364-371.

Stavely, J.R. and Main C.E. (1970). Influence of temperature and other factors on initiation of tobacco brown spot. *Phytopathology* 60: 1591-1596.

Strange, R.N., and Subba Rao, P.V. (1994). The phytoalexin response of groundnut and its role in disease resistance. *Oleagineux* 49: 227-233.

Subrahmaniyam, P. and Mc Donald, D. (1983). Rust diseases of groundnut. Information Bulletin No.13. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India.

Subrahmaniyam, P. and Mc Donald, D. (1987). Groundnut rust disease: Epidemiology and control. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), 1987. Groundnut rust disease proceedings of Discussion Group Meeting, 24-28, September 1984. ICRISAT Center, Patancheru, A.P., India.

Subrahmaniyam, P., Mc Donald, D., Waliyar, F., Reddy, L.J., Nigam, S.N., Gibbons, R.W., Ramanatha Rao, V., Singh, A.K., Pande, P.M. and Subba Rao, PV. (1995). Screening methods and sources of resistance to rust and late leaf spot of groundnut. *Information Bulletin No.* 47, ICRISAT, Patancheru, A.P., India, 20 pp.

Subrahmaniyam, P., Rao, V.R., Mc Donald, D., Moss, J.P. and Gibbons, R.W. (1989). Origin of resistance to rust and late leaf spot in peanut (*Arachis hypogaea* L.). *Econ. Bot.* 43: 444-445.

Subrahmaniyam, P., Reddy, D.V.R., Sharma, S.B., Mehan, V.K. and Mc Donald, D. (1990). A world list of groundnut diseases. Legumes Pathology Progress Report 12, Patancheru, A.P., India.

Subrahmaniyam, P., Reddy, L.J., Gibbons, R.W. and Mc Donald, D. (1985). Peanut rust: a major threat to peanut production in the semi arid tropics. *Plant Dis*. 69: 813-819.

Subrahmanyam, P., McDonald, D., Siddaramaiah, A.L. and Hegde, R.K. (1981). Leaf spot and veinal necrosis disease of groundnut in India caused by *Alternaria alternata*. *FAO Plant Prot. Bull.* 29: 74-76.

Sudheendra-Ashtaputre, Srikant Kulkarni, Ashtaputre, S. and Kulkarni, S. (1999). Effect of plant extracts and chemicals on late leaf spot of groundnut. *Karnataka J. Agric. Sci.* 12: 195-196.

Thai, C.N., Blankenship, P.D., Cole, R.J., Sanders, T.H. and Dorner, J.W. (1990). Relationship between aflatoxin production and soil temperature for peanuts under drought stress. *Trans. ASAE (Am. Soc. Agric. Eng.)* 33: 324-329.

Venkatesan, S., Raja, J.A.J., Maruthasalam, S., Kumar, K.K., Ramanathan, A., Sudhakar, D. and Balasubramanian, P. (2009). Transgenic resistance by N gene of a *Peanut Bud Necrosis Virus* isolate of characteristics phylogeny. *Virus Genes* 38: 445-454.

Vyas, S.C., Shastry, P.P., Shukla, B.N. and Varma, R.K. (1985). Two new leaf blight diseases of groundnut. *FAO Plant Prot. Bull.* 33: 121-122.

Woothisak, B., Sudthi, S. and Montien, S. (1991). Chemical control on peanut crown rot (*Aspergillus niger* L.) 10th Seminar on Thailand National Groundnut Meeting for Rayong (Thailand). 16-19 Oct 1991.

Collar rot: Pre-emergence rotting of seeds and post-emergence death of plants

Collar rot

Stem and pod rot

Stem rot - white mycelia growth and sclerotia

Dry root rot

Aflaroot

Early leaf spot – brown spot surrounded by yellow halo


Late leaf spot – dark brown irregular spots

Rust- orange colour pustules on lower leaf surface

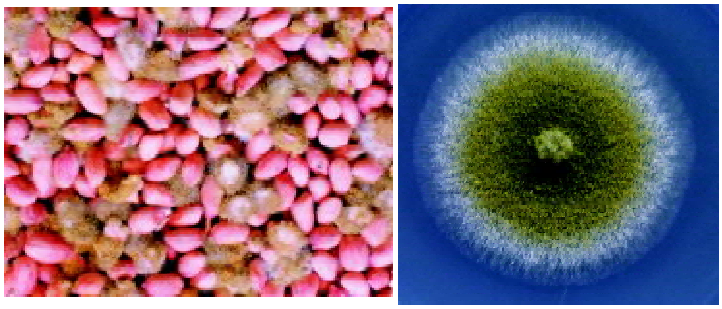

Alternaria leaf blight – blighting from tip and margin of the leaf


Bud necrosis - axillary shoot proliferation and necrosis of the terminal and axillary buds

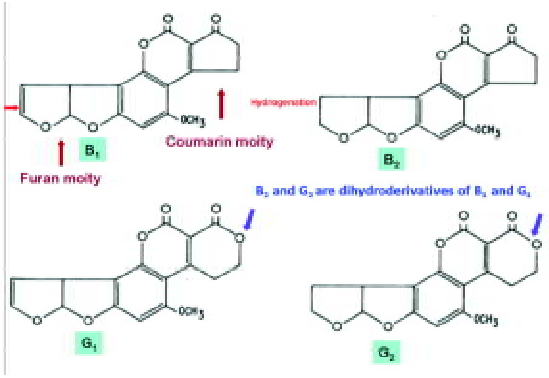

Groundnut Stem Necrosis (courtesy: ICRISAT)

Peanut Clump


Kalahasti malady- Brown lesions on the pod



Aspergillus flavus colonized kernel and the fungus in culture



Structure of four aflatoxins