EPIDEMIOLOGY AND MANAGEMENT OF RUST OF GROUNDNUT CAUSED BY *Puccinia arachidis* Speg. IN NORTHERN KARNATAKA

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By

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CERTIFICATE

This is to certify that the thesis entitled " **EPIDEMIOLOGY AND MANAGEMENT OF RUST OF GROUNDNUT CAUSED BY *Puccinia arachidis* Speg. IN NORTHERN KARNATAKA**" submitted by Mr. **GURURAJ SUNKAD** for the degree of **DOCTOR OF PHILOSOPHY (Agriculture)** in **PLANT PATHOLOGY** of the University of Agricultural Sciences, Dharwad, is a record of research work done by him during the period of his study in this University, under my guidance and supervision and the thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles.

DHARWAD
20th September, 2004

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4. **(S. N. MEGERI)**

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INTRODUCTION

I. INTRODUCTION

Groundnut [*Arachis hypogaea* L.) is considered as 'poor man's badam', due to its dual qualities *viz.*, high oil (48%) and protein content (26%). The kernel contains carbohydrates (17%), minerals (Zn, Ca, Mg, P and Fe), vitamins (A, B, B_{12} & E) and amino acids having high nutritive value. Besides these, testa (seed coat) and shell of pod contain 12 and 1 per cent fats, respectively (Plate 1).

Groundnut is one of the five important major oil seed crops of the world. It is grown in about 26 million ha with a production of 34.5 million t. India holds a premier position in global oilseed scenario accounting for 28 per cent of total oilseed area and 35.70 per cent of oilseed production in the country (Anon., 2002). At present, the crop occupies in an area of 7.60 m. ha. with a production level of 7.80 million tones of nuts-in-shell (Anon., 2003).

The critical assessment of groundnut production scenario in the country revealed that, Technology Mission on Oilseed Production era (1986-87 to 1996-97) witnessed an increase in area, production and productivity to the tune of 10.80, 33.50 and 37.20 per cent, respectively. However, despite this positive growth, the contribution of groundnut in terms of area and production to the total oilseeds in the country has declined by 5 and 3 per cent, respectively during the last five years (Anon., 2003). In addition to these, the cost of groundnut cultivation is also rising and is highest among the oilseeds. The groundnut productivity shows upward movement of national average from 750 kg/ha during 1970's to 1000 kg/ha during

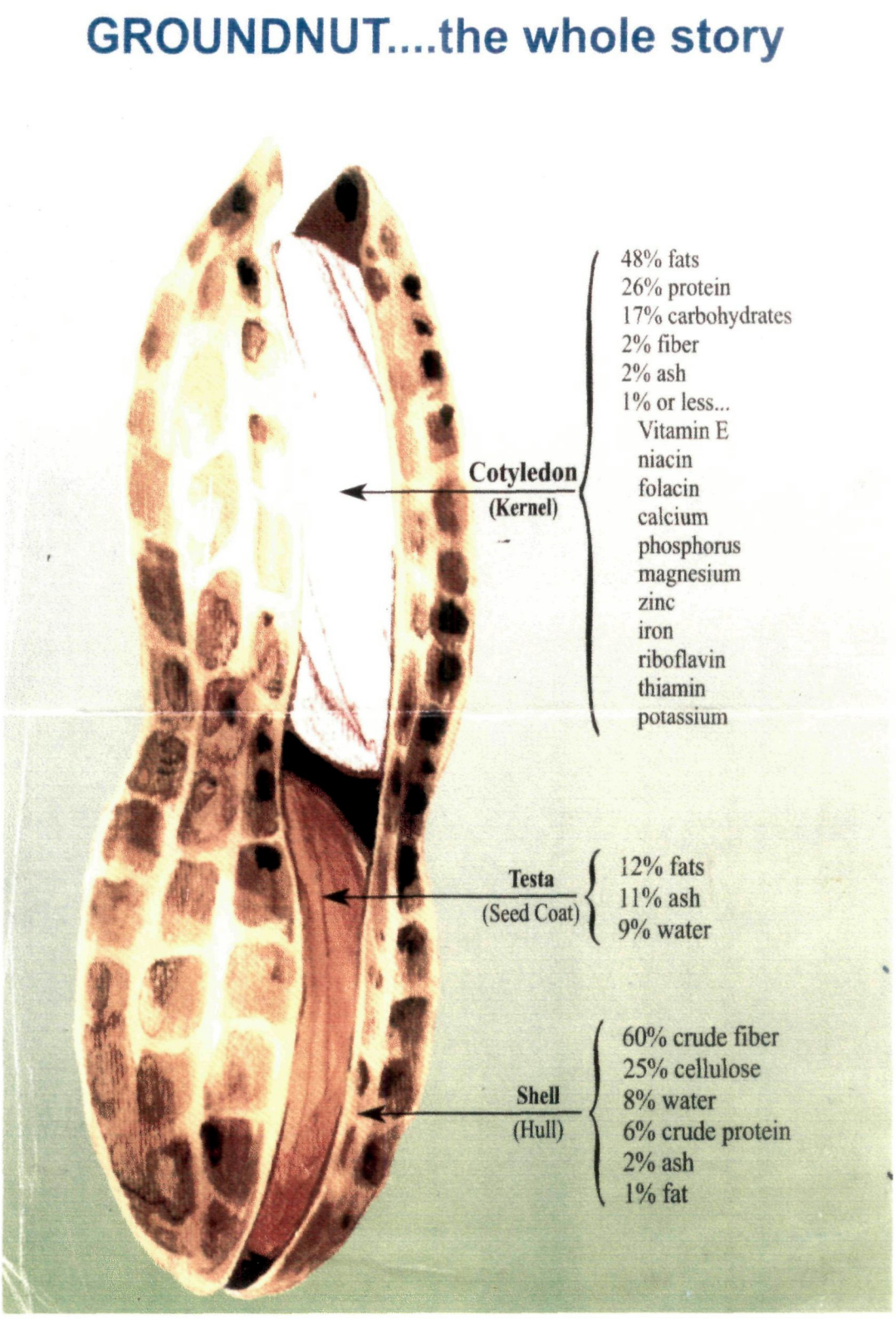

Plate 1. The whole nutritional story of groundnut.

2001-02 (Anon., 2002). Under these circumstances, it would be difficult to meet the projected demand of 12 million t of nuts-in-shell by the end of tenth five year plan period. With the liberalization process under WTO regime, groundnut has to face tough competition with the availability of cheaper edible oils from non-conventional sources like rice-bran, palm, sunflower, cotton seed and soybean. It has become difficult to sustain production and productivity levels due to vagaries of monsoon coupled with various biotic and abiotic stresses.

In Karnataka, the crop is grown over an area of 10.63 lakh ha with production of 10.81 lakh tones and the productivity in the state being 1070 kg/ha (www.raitamitra.kar.nic.in). Among biotic stresses, the diseases play an important role in declining area, production and productivity of groundnut. More than 55 pathogens have been reported to affect groundnut crop (Ghewande *et al.*, 2002). In recent years, groundnut rust caused by *Puccinia arachidis* Spegazzini has become one of the major diseases which was known to occur in many countries *viz.*, Asia, Australia, Oceana and Africa (Subrahmanyam and Mc Donald, 1983). It occurs in all the parts of the world, wherever groundnut is cultivated. The disease is most severe when intermittent rains with mean relative humidity above 87 per cent and average temperature of 23-24°C (Krishna Prasad *et al.*, 1979) prevails.

In India, the groundnut rust was first recorded from Ludhiana of Punjab state in 1969 (Chahal and Chohan, 1971) and subsequently, it was observed at Madras (Chennai) in Tamil Nadu (Bhama, 1972), Kolkota in West Bengal (Sharma and Mukherji, 1972), Coimbatore in Tamilnadu (Shanmugam *et al.*, 1972), Hyderabad in Andhra Pradesh

(Ramakrishna and Subbaiah, 1973) and Dharwad in Karnataka state (Puranik *et al.*, 1973).

The loss caused by groundnut rust is proportional to the disease severity and varies remarkably depending on the stage of infection, genotypes and environmental conditions. Severity of the disease is reported to cause yellowing, premature drying and defoliation. Usually on the lower surface of the leaves, small yellow lesions appear in the beginning which later develop into orange coloured pustules. *Puccinia arachidis* is known to produce dark cinnamon brown raised pustules with ellipsoid or obovoid uredospores having fine echinulations. Yield reduction is characterised by reduced pod and haulm yield (Alabi *et al.*, 1993). In addition to direct yield losses, rust can lower seed quality by reducing kernel size and oil content (Ghewande *et al.*, 2002). The rust is most prevalent and affects the plant growth by reducing the available photosynthetic area by way of pustule formation, finally leading to abscission of leaflets and extensive defoliation. The disease has adverse effect on recovery of pods especially if harvest is very much delayed. In severe cases of the disease out break, quality of kernels and haulms are affected finally leading to substantial loss in yield.

Losses in yield due to rust have been estimated to be around 50 per cent and even greater loss in haulm yield. Mayee (1983) reported that, rust is an economically important disease in India and responsible for frequent outbreaks throughout the year. In Maharashtra, epidemic of rust disease appeared during 1976-77. Subrahmanyam *et al.* (1980) reported 52 per cent loss from Hyderabad. The disease can cause loss in pod yield of 49 per cent and also reduction in the kernel weight by 19 per cent (Ghuge *et al.*, 1981).

In Karnataka, losses up to 42 per cent due to rust have been reported (Siddaramaiah, 1983). Krishna Prasad *et al.* (1979) reported that, rust in Karnataka was severe and caused losses up to 29 per cent. Further, Benagi (1991) reported that, Raichur is the 'hot spot' for outbreak of rust. Now, the disease has become one of the major constraints for groundnut cultivation, particularly in Northern Karnataka. Pande and Narayan Rao (2000) recorded highest severity of 81-90 per cent and more recently, 11-80 per cent and 41-80 per cent disease index of rust have been reported in Koppal and Raichur districts, respectively (Anonymous, 2002).

A number of management approaches *viz.*, development of tolerant varieties, application of fungicides, cultural practices and combination of approaches leading to integrated management of the disease have been evaluated and recommended (Nigam *et al.*, 1991; Vidyasekharan, 1981; Adiver *et al.*, 1995 and Jadeja *et al.*, 1999). Inspite of all these measures, rust has been continued to be a major constraint in groundnut production. In addition, there are large variations among different genotypes and cultural practices in different regions. These spatial and temporal variations render it difficult to evolve a common management strategies to control rust epidemics. Therefore, it is necessary to know the severity of the disease and factors associated with them in different localities and to identify, develop and recommend cost effective methods suitable to each location looking into the prevailing conditions.

In Karnataka, systematic research work on important aspects of the groundnut rust and its pathogen have not been done. Realizing the potentiality of rust disease in causing huge economic losses, it was thought

necessary to initiate systematic studies, on different aspects of the disease as well as pathogen. It is necessary to conduct a survey of the disease, so that, its distribution and extent of its spread can be understood and hot spots can be located, which would also help in natural screening for Host Plant Resistance (HPR). The estimation of crop loss is an important parameter in determining the economic importance of the disease and in order to develop threshold for determining, when the exact cost effective management practices should be deployed.

Epidemiological studies play an important role to develop suitable prediction models in relation to disease incidence and environmental factors. The pathogen survives in different forms during unfavourable environmental conditions. The methods of survival and spread of the pathogen need to be worked out to delink the infection chain at appropriate time in order to manage the disease effectively. Understanding the mechanism of resistance and also host plant resistance through slow rusters are important components in the disease management, when vertical resistance in the varieties is not available.

A single method of management may not be possible to control this disease effectively. Therefore, it is necessary to develop an Integrated Disease Management (IDM) strategy having Host Plant Resistance (HPR), plant extracts and fungicides as efficient components.

Therefore, the present investigation was undertaken with the following objectives.

1. Survey, surveillance and mapping of groundnut rust endemic areas in Northern Karnataka.
2. Assessment of losses due to rust disease.
3. Epidemiology and spread of the disease with special reference to aerobiology, prediction and forecasting systems.
4. Histology, histochemistry and biochemical mechanism of disease resistance in groundnut varieties.
5. Studies on pathogenic variability in *Puccinia arachidis*.
6. Development of cost effective integrated disease management strategy for rust disease.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Groundnut rust caused by *Puccinia arachidis* Spegazzini is the most wide spread and an important foliar disease in Asia, Australia, Oceana and Africa (Hammons, 1977; Subrahmanyam *et al.*, 1979 and Subrahmanyam and McDonald, 1983). The disease is gaining more economic importance in all the groundnut growing areas of the world.

Literature is available on symptoms, distribution, disease development, survival of pathogen, aerobiology, disease prediction model, environmental effects on disease, biochemical basis of disease resistance and use of fungicides. However, literature available on collateral hosts, histology and histochemistry, exact crop loss assessment, slow rusting mechanism, variability in *P. arachidis* and integrated management of the disease is less and hence from related pathogens/diseases these aspects are also reviewed in the present study.

IDENTITY OF THE CAUSAL FUNGUS

The rust of groundnut caused by *P. arachidis* has been known to Mycologists since 1884 from specimens were collected from groundnut plants in Paraguay (Spegazzini, 1884). The fungus was studied by Gustav Lagerheim and recognized it as new species and published as *Uredo arachidis* Lagerheim in 1894 (Bhama, 1972). Later, Hennings (1896) described the rust fungus as *Uredo arachidis* Hennings. Spegazzini (1884) identified the rust specimen collection number 3449 of Caa-guazu, Paraguay, sent by French Botanist Benedict Balansa in Argentina and named it as *Puccinia arachidis* Spegazzini. The rust specimen consisted entirely of teliospores, the only stage that

Spegazzini (1884) described. West (1931) detected uredial stage of rust in Gainsville, Florida, USA and named it as *Pullularia arachidis* (Speg.) Arthur and Mains.

The rust sample collected from Santo Domingo in Central America in 1921 consisted of uredospores and teliospores. Another collection of rust from Gainesville, Florida by Hull and West contains both uredospores and teliospores (Hennen *et al.*, 1982). Chahal and Chohan (1971) reported the occurrence of teliospores of groundnut rust from Ludhiana, Punjab state, India on plants grown in a green house. Hennen *et al.*(1976) reported the occurrence of teliospores of groundnut rust developing within uredia on *Arachis hypogaea* after artificial inoculation in a green house at Sao Paulo, Brazil.

SYMPTOMATOLOGY

McVey and Donald (1965) described the sequence of symptoms expression as (1) whitish flecks on abaxial leaflet surface, (2) yellowish green flecks on adaxial surfaces and almost simultaneously, small orange pustules on abaxial surface, (3) opening of pustules on abaxial surface and (4) appearance of pustules on the adaxial surface. He also obtained pustules by inoculating adaxial leaflet surface. However, pustules from adaxial surface inoculation were fewer and were later in the developing stage than those from abaxial surface inoculation. Hammons (1977) observed that maximum severity of rust when groundnut was followed by groundnut. Infected crop matured two to three weeks early, leaves were completely killed, seed size was smaller, pods became detached in the soil, pod yield and oil contents were drastically

reduced. Singh (1978) described the symptoms on stem and also on pegs. Kenjale (1979) noted that, infection of groundnut by rust caused adverse effect on nodulation, chlorophyll content and dry matter weight of shoot, roots and oil content.

According to Subrahmanyam and McDonald (1983), rust disease can readily be recognized when the orange coloured pustules or uredia appear on the abaxial (lower) surface of the leaves and ruptures to expose masses of reddish brown uredospores. The wind distributed uredospores land on the leaf surface and if temperatures is in the range of 15-30°C and leaves are wet with dew or rain, and the uredospores germinate and produce appressoria and infection hyphae that penetrate the leaf through the stomata. The incubation period ranges from 9 to 20 days, being greatly influenced by environmental factors and host reaction. Pustules appear first on the abaxial surface and, in highly susceptible cultivars, the original pustules may be surrounded by colonies of secondary pustules. Pustules may later be formed on the adaxial (upper) surface opposite to those on the abaxial surface. The pustules are usually circular and range from 0.5 to 1.4 mm in diameter. They may be formed on all aerial plant parts apart from flowers and pegs in contrast with the rapid defoliation associated with leaf spots. Leaves infected with rust become necrotic and dry up, but tend to remain attached to the plant.

SURVEY, DISTRIBUTION AND ECONOMIC IMPORTANCE

The disease has been known to mycologists for a century since Spegazzini named and described the disease from *Arachis* material collected by B. Balansa in 1982 near Caa-guazu, Paraguay (Spegazzini, 1884). Within 40 years, the disease has become established from Argentina and Peru north through the groundnut growing areas of South and Central America and into West Indies (Bromfield, 1971 and Hammons, 1977). Prior to 1969, the disease was largely confined to south and Central America, with occasional outbreaks occurring in the southern most groundnut producing areas of the USA. The disease was also recorded in China (Tai, 1937), but did not become permanently established. Now, the disease has spread to and became established in many countries in Asia, Australia, Oceana and Africa (Subrahmanyam, *et al.,* 1979 and Subrahmanyam and Mc Donald, 1983).

The disease and the fungus have been reported from all parts of the world, wherever groundnut is grown. It was recorded from Jamaica (Hansford, 1924), Brazil (West, 1931), USSR (Bromfield, 1971), Texas (Kenlenight, 1941), Nicaragua (Litseaberger and Stevenson, 1951), Malaysia (Said and Sharom, 1971), Korea (Anonymous, 1973), Philippines (Bromofield, 1971) and Indonesia (Triharsa, 1972). Gibson and Waller (1973) reported the spread of *P. arachidis* throughout the South East Asia and also recorded the disease in Japan, Thailand, Malaysia and India. It was also recorded from Malavi (Reddy, 1976), Zambia (Raemaekers and Preston, 1977) and Taiwan (Fang, 1977).

The reported losses of pod yield caused by the pathogen in different groundnut growing countries compiled and given below.

Sl. No.	Name of the country	Per cent yield loss	Reference
1.	Mauritius	70	Felix and Ricand (1977)
2.	Australia	100	Middleton & Shorter (1987)
3.	Thailand	27-85	Wongkaw *et al.* (1987)
4.	Nigeria	0.7–1.4 t/ha	Salako and Olorunju (1987)
5.	China	15-59	Zhou Liang Gao (1987)
6.	India		
	Karnataka	11-80	Krishna Prasadand and Siddaramaiah (1977)
	Maharashtra	50	Mayee (1983)
	Andhra Pradesh	52	Subrahmanyam et al.(1980)
	Bihar	22 – 29	Singh (1978)

In India, rust was observed for the first time on groundnut in an experimental field at Punjab Agricultural University, Ludhiana (Chahal and Chohan, 1971). Subsequently, the disease was observed in the Maduravoyal field laboratory of the Botany Department, University of Madras by Bhama (1972). Further, Sharma and Mukherji (1972) observed the incidence of rust on 45 days old plants grown on pots in the green house of State Agricultural Research Institute, Culcutta. The disease was also reported on groundnut plants grown in small pots at Central Farm of Tamil Nadu Agricultural University, Coimbatore (Shanmugam *et al.*, 1972). Ramakrishna and Subbayya (1973) observed the disease on green house grown plants at Agricultural College, Tirupati. Later, it was recorded simultaneously from four locations in Maharashtra (Patil and Kalekar, 1974).

The disease assumed epidemic proportions in 1976 in Maharashtra (Garud *et al.*, 1976). During this period, the production was declined by 35 per cent (Mayee, 1978). Puranik *et al.* (1973) observed rust on potted plants at Main Research Station, Dharwad and also in the specimens collected from fields of Bijapur and Belgaum districts of Karnataka. Later, Krishna Prasad and Siddaramaiah (1977) reported rust on 50–90 days old plants from Dharwad.

Rust was particularly serious in Tamil Nadu, Andhra Pradesh, Karnataka and Maharashtra States, probably because of extensive and continuous cropping (Subrahmanyam *et al.*, 1979). Survey conducted by the National Research Centre for Groundnut, Junagadh during *kharif* 1980-83 revealed that, the rust with moderate to heavy severity was distributed in all groundnut growing districts of Saurashtra region of Gujarat (Ghewande and Misra, 1983).

Siddaramaiah *et al.* (1979a) conducted survey in different parts of Karnataka and reported that, rust incidence was high during 1978 in northern districts of Karnataka. Benagi (1991) recorded the severe rust disease incidence (>35 per cent) and reported that, Raichur is the hot spot for out break of rust. Now, the disease has become a major constraint for groundnut cultivation, particularly in northern Karnataka. Pande and Narayan Rao (2000) recorded highest severity of 81-90 per cent and more recently, 11-80 per cent and 41-80 per cent disease index of rust have been reported from Koppal and Raichur districts, respectively (Anon., 2002).

Losses in yield due to rust have been estimated to be around 50 per cent and an even greater loss in haulm yield. Yield losses up to 70 per cent due to

combined infection of rust and leaf spot pathogens have been reported in India (Subrahmanyam *et al.*, 1984). Losses recorded due to rust is as high as 50 per cent of seed yield and even more for haulms (Alabi *et al.*, 1993). Kenjale (1979) observed significant decrease in the pod yield and dry matter yield of plant due to rust infection. Yield reduction was characterized by decrease in pod yield and dry matter yield.

Mayee (1978) reported that, rust is an economically important disease in India and responsible for frequent epidemics throughout the year. In Maharashtra, epidemics of rust disease was appeared during 1976-77. Subrahmanyam *et al.* (1980) reported 52 per cent loss from Hyderabad. On SB-XI variety, rust caused 49 per cent losses in pod yield and reduced the kernel weight by 19 per cent (Ghuge *et al.*, 1981). Zhou Liang Gao (1984) reported that, groundnut rust can cause losses ranging from 15-59 per cent. Further, he made artificial inoculation at flowering, pegging, pod initiation and middle of pod initiation stages of growth and resulted in yield losses of 49, 41, 31 and 18 per cent, respectively.

Subrahmanyam *et al.* (1984) reported that, yield losses due to rust were less (6-12%) in the resistant varieties than the susceptible ones (40-77%). When initial rust incidence and further development were manipulated by chemical spray schedules, the loss in pod yield ranged from 4.8-71.9 per cent, while kernel weight reduced from 1.6-34.1 per cent (Mayee, 1978 ; 1983). Siddaramaiah (1983) reported that, avoidable losses up to 42 per cent

by rust in groundnut. Frequent rust epidemics have discouraged its cultivation on a large scale in India (Mayee, 1987).

LOSS ASSESSMENT

The need for reliable crop loss assessment methodology assumes added importance about improving or maintaining environmental quality by reducing the use of pesticides (Stern *et al.*, 1959). Benagi (1995) opined that, defoliation due to late leaf spot in groundnut was maximum (49.95%) at 100 days after sowing (DAS) in control plot, whereas, it was only 2.82 per cent in six sprays received plots. Less than 10 per cent defoliation was observed in three, four, five and six sprays received plots. Patil (1996) reported that per cent disease index consequent to different fungicidal sprays of Mancozeb (0.2%) was least in plots which received six sprays and maximum in control plots of sunflower due to rust. He also mentioned that, compared to six sprays received plot, the loss of seed yield due to rust was maximum (27.02%) in control. Whereas, it was 22.57, 18.75, 12.03, 12.35 and 2.26 per cent in one, two, three, four and five sprays received plots, respectively. Hundekar (1999) reported that, three sprays of hexaconazole at 35, 50 and 65 days after sowing were required to manage soybean rust in susceptible variety JS-335 whereas, two sprays at 35 and 50 days after sowing were sufficient for PK-1029, a moderately resistant variety in severe rust prone area. The highest benefit cost ratio of 3.44 was obtained with three sprays of hexaconazole on JS-335 whereas, 3.40 with two sprays of hexaconazole in PK-1029.

Crop loss model

Crop loss models are essential for estimation to know the loss due to the disease. Accurate information, concerning losses is needed by growers and

plant protection specialists to develop decision thresholds for determining when the cost effective control measures should be deployed (Nutter, 1993). Benagi (1995) estimated groundnut pod yield loss due to late leaf spot of groundnut by developing crop loss model in the form of Y=1.318 + 0.03 (AUDPC) with coefficient of determination of 97.80 per cent. Similarly, a crop loss model in the form of Y=3.49-0.558 (AUDPC) with coefficient of determination of 96.0 per cent was developed to estimate yield loss due to sunflower rust (Patil, 1996).

Hegde (2001) estimated soybean yield loss values due to rust by developing yield loss model in JS-335 and PK-1029 varieties using Per cent Disease Index (PDI) as input variable in the form of Y=135.77-5.332 (PDI) with R = 0.86 (for JS-335 variety) and Y=34.13-0.921 (PDI) with R=0.98 (PK-1029).

EPIDEMIOLOGICAL STUDIES

Disease development

Castellani (1959) reported that, groundnut rust pustules did not develop when adaxial leaflet surface was inoculated. On the contrary, McVey and Donald (1965) obtained positive results in peanut for development of pustules by inoculating adaxial leaflet surface. However, pustules from adaxial surface inoculation were fewer and slow in development than from abaxial leaflet surface inoculation.

Mallaiah and Rao (1979) reported that first symptoms of infection on potted plants was the appearance of whitish spots on abaxial surface of leaflets which appear six days after inoculation. These spots turned yellowish green in the next two days and first eruption of uredia occurred 7-8 days after inoculation. The plants which are of 10-70 days old were found susceptible,

but coalescence of pustules and early leaf fall were higher on younger plants. However, number of pustules developing on leaflets were higher on 40-50 days old plants. But, the pustules on adaxial surface always appear one or two days late than those on abaxial surface and mostly occurred opposite to those on lower surface.

Siddaramaiah and Hegde (1979) reported that, uredospore germinate within three days in water medium and penetration of host was either through the stomata or directly through epidermis. They also observed that higher germination and infection occurred in the abaxial leaflet surface.

Viability and survival of *P. arachidis*

Mayee *et al.* (1977) predicted that, groundnut rust has a definite pattern of movement in India. In southern states, it is present throughout the year as the inoculum on crop is available throughout the year compared to lesser degree as in central India. The additional introductions of wind borne spores occur on crops from south. Further, they reported that rust is unlikely to over summer in crop debris under hot climatic conditions in Uttar Pradesh, Bihar, Haryana, Punjab, Rajasthan and north Madhya Pradesh as the groundnut is grown in these areas only in the rainy season. The inoculum probably reintroduced annually from south to central India.

Mallaiah and Rao (1979) found that, the uredospores remained viable upto four weeks, when stored at temperatures below 30°C but lost viability within two weeks when stored at temperature above 35°C. Uredospores of *P. arachidis* were survived for 39 and 47 days in winter months; for 43 and 51 days in monsoon and for 34 and 49 days in summer months under cage and room temperatures respectively (Lingaraju *et al.*,1979).

Subrahmanyam *et al.* (1980) reported that, viability of uredospores from surface contaminated pods and seeds stored at room temperature decreased from an original 95 per cent to zero after 45 days. In another report, uredospores in exposed crop debris survived for only four weeks, while at 40° C they lost their viability within five days, but at low temperature of –4°C they did not loose viability (Subrahmanyam and McDonald, 1982). They also opined that, the practice of continuous cultivation of groundnut in southern India is an important factor in perpetuation of *P. arachidis* in India.

Patel and Vaishnav (1986) reported that, the uredospores in infected groundnut plant debris kept in a cage outside and in an open heap lost viability after 25 days. Uredospores remained viable for 35 days in a heap in the shade, 45 days in the laboratory and 55 days in a refrigerator at 6°C. Patel and Vaishnav (1989a) reported that, uredospore infection can carry the rust from one groundnut crop to another throughout the year. Benagi (1991) reported that, maximum germination of uredospores of *P. arachidis* was observed at the temperature range of 5- 35°C , but optimum temperature was 25°C. Further, he reported that, uredospores cannot survive beyond 40°C in nature. Patil *et al.* (1997) reported that no germination of uredospores was observed for a single day under freeze and deep freeze conditions. This might be due to the fact that lower temperature causes freezing injury for the germination of uredospores.

Self sown groundnut plants/collateral hosts

Bromfield and Cavario (1970) tested several legumes against *P. arachidis* and reported that none of them developed rust infection.

Subrahmanyam and Mc Donald (1982) reported that, the pathogen survives from season to season on voluntary groundnut plants. Further, they examined various crops and weeds for rust infection and inoculated some of them with uredospores of *P. arachidis* in glasshouse. No infection was recorded on any of the plant species.

Search for telial stage of *P. arachidis*

P. arachidis is known almost exclusively by its uredial stage (Mayee, 1987). There are few records of the occurrence of telial stage on cultivated groundnut and wild *Arachis* species (Chahal and Chohan, 1971 and Hennen *et al.,* 1976). Mayee (1987) made attempts to induce telial stage formation by modification of environmental factors and failed. Further, he reported that, uredospores were the main, if not the only, means of rust carry over and dissemination in India.

Effect of temperature levels on germination of uredospores

Temperature is one of the important external factor, which influence the spore germination. Fang (1982) claimed that, uredospores of groundnut rust germinated between 15-30^{o}C and optimum was 20-25^{o}C. Harrison (1972) reported that, the production of self inhibitors play an important role in reducing germination of uredospores of *P. arachidis*..

Subrahmanyam and McDonald (1987) reported that, the temperatures in the range of 20-25^{o}C were optimum for germination of uredospores of *P. arachidis.* The maximum germination (91.00%) of uredospores of *P. arachidis* occurred at 25^{o}C and decreased with increase or decrease in temperature. Rao *et al.* (1997) reported that temperatures in the range of 20-30^{o}C were

favourable for germination, the optimum being 25°C. Srikanta Das *et al.*, (1997) showed that, uredospore germination occurred at 100 per cent RH and a temperature of 25±2°C within 2 hrs. Maximum per cent uredial germination occurred within 25 hrs at a temperature of 20°C. Temperatures below 10°C and above 30°C inhibited uredial germination. At low temperature (5°C), urediospores remained viable for 65 days but at 40°C viability was lost rapidly.

Effect of incubation period on germination of uredospores

Mallaiah and Rao (1979) observed germination of uredospores of *P. arachidis* within two hours and reached maximum level within six hours. Munde and Mayee (1979) reported that, incubation period increased with increase in temperature. AT 23°C, the incubation period was 6 to 9 days, it was 8 to 10 days at 27°C and 11 to 19 days at 30°C. Benagi (1991) reported that, incubation period of 6 hrs was required for maximum germination of uredospores of *P. arachidis.*

Effect of humidity in relation to disease development

Cochrane (1958) reported that, free water was essential for uredospore germination of *P. arachidis.* For good germination, 80 per cent relative humidity was necessary (Rao et al., 1997 and Mallaiah and Rao, 1979). Relative humidity above 85 per cent favoured outbreak of rust and severe infection was observed when relative humidity was 74-89 per cent (Patel and Vaishnav, 1989b).

Effect of age of plant in relation to infection of *P. arachidis*

Mallaiah and Rao (1979) reported that, plants which varied from 10 to 70 days in age were found to be susceptible to rust infection. However, they

have observed that, the number of pustules were higher on 40 to 50 days old plants.. Munde and Mayee (1980) observed that, younger leaves gave better rust development as compared to the older ones. Plants of all age groups were susceptible to rust infection, but there was difference in the intensity of rust for leaflet and maximum intensity of rust was observed on 60 days old plants (Patel and Vaishnav, 1988).

Effect of date of sowing on the incidence of groundnut rust

Naidu and Chandrika (1997) reported that, early sown crop (9th June) suffered least from rust diseases due to low inoculum potential. Whereas, late sown crops suffered more because of ready availability of inoculum built on early sown crops. They reported that, best sowing times to avoid rust and to obtain maximum pod yields are early June and July sowings (Srikanta Das *et al.*, 1999).

Aerobiology

The spores of certain fungi are disseminated by air current in nature. Stakman *et al.* (1923) studied the dissemination of spores by air currents and attempted to correlate the data with the spread of rusts. Mehta (1940 & 1952) concluded that, the spores were present in the atmosphere well in advance of the actual outbreak of the disease by exposing vaseline coated slides to trap spores of cereal rusts.

Kulkarni and Ramakrishnan (1977) used Burkard volumetric spore trap and observed diurnal and seasonal variations in spore number in the atmosphere and noticed the influence of favourable humidity and temperature on the sporulation and spore discharge of *Drechslera oryzae.*

Feakin (1973) classified groundnut rust *P. arachidis* as airborne disease and opined that, aerial dissemination is of paramount importance for groundnut rust as the uredinial stage is the only stage of *P. arachidis* found in most parts of the world. Mayee and Ekbote (1983) recorded high spore counts of groundnut rust during September at Parbhani in Maharashtra. Benagi (1991) reported that, number of uredospores of *P. arachidis* in the atmosphere showed considerable daily fluctuation with weather factors. Dissemination of uredospores in the atmosphere was more in between 80 and 85 per cent relative humidity and temperature of 29 to 30°C.

Mallaiah and Rao (1982 and 1987) reported that, *P. arachidis* uredospores were dispersed very efficiently by air. Air borne concentration follow the pattern of field disease incidence and can be used to assess the severity. High concentration occur when temperature is 29–31°C and relative humidity 75–85 per cent.

Galgunde and Kurundkar (2002) reported that temperature and rainfall were found to influence the deposition pattern as indicated by correlation analysis. Humidity and temperature were negatively correlated, whereas rainfall was positively correlated with the incidence and intensity of rust of groundnut.

Effect of environmental factors on development and severity of rust

Environmental factors decide the epidemics of groundnut rust. The environmental factors *viz.*, temperature, relative humidity and rainfall are important for disease development and these environmental factors are being used to forecast disease severity.

Krishna Prasad *et al.* (1979) reported that, intermittent rains with mean relative humidity above 87 per cent favoured the disease initiation. Rust development was proportionately better with every increment of the time of free water availability (Munde and Mayee, 1980). Patel and Vaishnav (1989b) reported that, severe rust infection was associated with a temperature of 25-29°C, relative humidity 74-89 per cent and 10-13 mm rainfall during the preceeding week. Lokhande *et al.* (1998) reported that, rainfall of 200 mm was congenial for disease development..

Disease prediction model

Benagi (1995) developed logistic models for predicting late leaf spot of groundnut.

$$\hat{Y}_t = \frac{100}{1 + e^{4.092 - 0.466\,t}} \quad \text{for } \textit{kharif}, 1993$$

$$\text{and } \hat{Y}_t = \frac{100}{1 + e^{4.206 - 0.466\,t}} \quad \text{for } \textit{kharif}, 1994$$

Srikanta Das *et al.* (2000) used stepwise multiple regression analysis to identify the relationship between severity of rust of groundnut and also weather parameters and they reported that, maximum temperature, minimum temperature, maximum relative humidity and minimum relative humidity were highly correlated with the disease.

STANDARDISATION OF INOCULATION TECHNIQUES

Maintenance and multiplication of inoculum of the pathogen is essential for various studies. Since *P. arachidis* is an obligate parasite, it has to be maintained on its host.

Chirame *et al.* (1997) revealed that, for mass inoculation, spraying of aqueous uredial suspension after making injuries was observed to be the most convenient method in creating artificial epiphytotic of the disease. Singh and Thapliyal (1977) found that, spraying, dusting and needle application of uredospores of *Phakopsora pachyrhizi* Syd. were successful methods of inoculation to maintain inoculum. However, they suggested spraying of inoculum is a convenient method, for large scale maintenance and multiplication. Dadke (1996) and Hegde (2001) reported that, stapler method was the best method of inoculation for maintenance and multiplication of *P. pachyrhizi.*

HISTOLOGY AND HISTOCHEMICAL STUDIES

Few studies have been made pertaining to histological and histochemical changes due to infection of *P.arachidis* in the host. Hence, the work done on other crops/pathogen is reviewed.

Kaur and Dhillon (1988) reported that, epidermal and mesophyll cells were shrunken or collapsed, damage to protoplast was more obvious than damage to cell walls in the leaf tissues infected by *Cercospora arachidicola* in groundnut. The histochemical localization revealed, gradual depletion of polysaccharides, proteins and nucleic acids from the diseased host tissue. Vijayakumar (1990) reported declined polysaccharides, proteins and RNA in groundnut leaves infected with *Cercospora arachidicola* (Berk. & Curt.) v. Arx.

MECHANISM OF RESISTANCE

Physiological basis of resistance

Morphophysical parameters

The morpho-physiological studies such as cuticular thickness, epidermal cell thickness, epidermal cell number, size and number of stomata related to

disease resistance against groundnut rust are meager. Hence, the information available in other field crops with respect to diseases and pest are also reviewed here under.

Epidermis

Earlier investigators observed that, thickness of epidermal cell wall plays an important role in determining susceptibility of the host to pathogen invasion (Veeraraghavan, 1983). Mayee and Apet (1995) reported thicker epidermis cum cuticle in resistant varieties as compared to susceptible varieties of groundnut to rust pathogen. Similar results were reported by Mayee and Suryavanshi (1995) against late leaf spot of groundnut. Bhat Tanmai (1997) reported that, groundnut varieties resistant to late leaf spot were characterized by more number of epidermal cells and epidermal thickness compared to susceptible varieties.

Size and number of stomata

Size and frequency of stomata play an important role in determining susceptibility of the host to pathogen invasion (Hart, 1929 and Hooker, 1967). Frequency of stomata was significantly lower in leaf spot resistant groundnut genotypes as compared to susceptible ones (Benagi, 1995). Resistant genotypes against rust were characterized by smaller and fewer stomata on surfaces of leaves (Mayee and Apet, 1995; Mayee and Suryavanshi, 1995).

Epicuticular Wax

The waxy layers besides offering a mechanical barrier which cannot be rendered soluble by the enzymatic action of the germ tubes of the fungus seems to contain substances which inhibit bacterial, fungal and insect attack (Chibnall and Piper, 1934). Benagi (1995) reported that, the wax content was

least in susceptible variety as compared to resistant variety for late leaf spot of groundnut. He also stated that, the wax content decreased drastically in susceptible variety due to infection while it increased in resistant varieties.

Biochemical basis of resistance

Soluble sugars

In susceptible genotypes disease development was more whereas, the mean sugar content come down at later part of the crop growth. This indicated the utilization of these sugars by the invaded pathogens for their nutrition. Such nutritional utilization of sugars by the invading pathogens has been reported earlier also (Krog *et al.*, 1961).

In general, infection by some pathogens bring about lot of changes in the respiratory pathway and photosynthesis which are the vital processes in the plants. This leads to fluctuation in sugars in the plant system (Klement and Goodman, 1967). Subrahmanyam *et al.* (1976) reported that, total soluble sugar were accumulated in leaves infected by *P. arachidis*. Remarkable increase in protein content and water soluble sugars were reported in the severely rust infected leaves (Siddaramaiah *et al.*, 1979b). Total sugars increased in susceptible inoculated plants compared to susceptible healthy ones.

Total phenol and orthodihydroxy phenol

Infection in certain diseases is characterized by increased synthesis of certain precursor of phenolic compounds, which exhibit more toxicity to pathogen than their reduced forms. In many instances, there have been a positive correlation between the amount of phenolic content and degree of resistance to plant disease.

Ekbote and Mayee (1983) reported an increasing trend in total phenolics in groundnut varieties which are resistant to rust. Reddy and Ravindranath (1988) reported that, infection of *P. arachidis* on resistant varieties *viz.*, ICG-7013 and ICG-7885 was accompanied by an increased synthesis of total phenols in plant tissues. The reverse, however was true in susceptible TMV-2 where total and orthodihydroxy phenol synthesis decreased during lesion development.

The changes in phenol content in groundnut leaves in response to infection by *P. arachidis* was studied in resistant ALR-1 and susceptible JL-24 and TMV-12 varieties by Velazhahan and Vidhyasekaran (1994). They reported that, total phenol and orthodihydroxy phenol contents of the resistant variety were higher throughout the growth period as compared to susceptible varieties. Kumar and Balasubramanian (2000) inoculated two *P. arachidis* susceptible cultivars *viz.*, TMV-1 and VRI-2, and two resistant donors *viz.*, ICG-1697 and ICG-10053 with uredospores and reported that, accumulation of total phenols was at a faster rate in the resistant varieties than the susceptible ones.

Protein

The protein biosynthesis of the host is widely assumed to be significant feature of pathogenesis, particularly during incompatible reaction. Quantitatively speaking, the total protein synthesis is much enhanced in the healthy tissues around the infected tissues. This additional protein considered to be entirely of host origin (Dasgupta, 1988). Patel and Vaishnav (1986) reported increase in protein content in groundnut leaves infected with rust as compared to healthy leaves. Narayan Reddy and Khare (1988) reported that,

goundnut varieties *viz.*, Jyothi (highly susceptible) and ICG-1697 (resistant) were inoculated by spraying with fresh uredospore suspensions of *Puccinia arachidis* and found increased total sugars and phenols.

STUDIES ON VARIABILITY IN *P. arachidis*

Cook (1972) stated that, *P. arachidis* probably exists in more than one racial form. Bromfield and Cevario (1970) collected different isolates from two widely separated geographical sites and named as PR 1-66 and Tex. 2-67 and screened for accession number of *Arachis* Spp. They observed that, accession PI-314917 and PI-315608 were physiologically resistant to both the cultures but they could not be separated into two physiologic races on the basis of reaction. On the basis of variation in reaction between two rust isolates, Hammons (1977) supported existence of physiologic forms in *P. arachidis*. Similar observations were also noticed by Mayee *et al.* (1979) on the basis of variation in reaction on the same varieties exposed for two years. When the same set of genotype were subjected to screening for two years, some genotypes showed resistance for one year and susceptible reaction in the second year and vice versa. This variation in reaction was attributed to existence of physiologic form of *P. arachidis*. The pathogenic variability in rust of groundnut has neither been unequivocally confirmed nor completely ruled out.

Thermosensitivity of three isolates collected from different agro ecological regions of India differed when inoculated on detached leaves of SB-XI variety (Munde and Mayee, 1979). A set of 196 groundnut genotypes comprising resistant, moderately resistant and susceptible reactions were planted at four locations in Maharashtra. Although no major differences in the level of resistance were noted, the AUDPC varied for genotypes, indicating the

possibilities of ecotypes in the rust population (Mayee, 1987). Kalekar (1983) made an attempt to select the host differential varieties and to study physiologic forms in groundnut rust cultures. He selected 15 genotypes of groundnut as differentials and reported that, all 10 rust cultures behaved differentially. Among them, Pune culture was most virulent and Aurangabad culture was least virulent. However, the shape, size, colour etc. of uredospores did not correlate with the virulence of the culture. Patil (1996) studied variation in 16 isolates of *P. helianthi* and reported that, no variation in morphological characters of colour of pustules and colour of uredospores. But, he observed little variation in size of uredospores of isolates tested.

SLOW RUSTING MECHANISMS IN GROUNDNUT GENOTYPES

The term '**slow rusting**' describes the ability of a cultivar to retard rust development. It is also a useful measure of resistance as it is the result of all factors that influence disease development such as difference in environment, variety and population of the pathogen (Wilcoxson, 1986). Slow rusting resistance can be recognized by various mechanisms such as increased latent period, infectability, pustule size and sporulation. The apparent infection rate "r" is calculated by using the formula as proposed by Van der Plank (1963) and it is being widely used to reorganize partial resistance or slow rusting type of resistance (Luke *et al.*, 1975 and Gupta and Singh, 1982).

Lot of work has been done on slow rusting mechanism in cereals such as wheat, barley and oats (Ohm and Shaner, 1976; Andres and Wilcoxson, 1984; Nargund, 1989) while some work has been done in crops like maize and sorghum (Pataky, 1986). Very few studies have been done on slow rusting mechanisms in groundnut. Hence, an attempt was made here to review the important contributions on this line on rust of other crops.

Apparent infection rate of disease (r)

The mathematical approach of Van der Plank (1963 & 1968) to the analysis of epidemics suggested the requirement of slower infection rate (r) for characterization of slow rusting genotypes. Nargund (1989) studied the rate of spread of leaf rust per unit per day in wheat varieties. The variety Raj-1555 and Kalyansona and Sonalika showed maximum rate of spread. Raju and AnilKumar (1990) pointed out, "r" values were not as useful as AUDPC values in studying the slow rusting mechanism. Chandramouli (1992) while working with cowpea rust identified V-16, V-37, V-70, V-118, V-240 and TVX-944 as slow rusters and C-152 and HG-171 as fast rusters by studying the "r" values at weekly interval.

Area Under Disease Progress Curve (AUDPC)

Several evaluations of disease during the development of epidemic were much essential in construction of disease progress curves. Data from disease progress curves may be reduced to single statistics to facilitate analysis of data by means of area under disease progress curve (Wilcoxson, 1986).

Nargund (1989) employed area under disease progress curve to evaluate bread wheat varieties against leaf rust. The wheat varieties *viz.*, AKW-65-1, Lal Bahadur and NI-5439 and local red and Amrut recorded higher value of AUDPC with lower seed yields. Chandramouli (1992) while working with cowpea rust identified the cowpea varieties V-16, V-70, TVX-944, V-37, V-188 and V-240 as slow rusters, C-152 and HG-171 as fast rusters and the rest as intermediate based on the AUDPC values.

Latent period (LP)

Latent period or incubation period was considered as an important component of horizontal resistance. The period between inoculation and the

appearance of symptoms on the host has been referred as latent period. Parlevliet and Van Ommersen (1975) pointed out that, the selection for slow rusting can be done by selecting cultivars possessing few or several components such as long latent period and less sporulation.

Chandramouli (1992) while working with cowpea rust noticed difference in latent period between fast rusting and slow rusting varieties. Varieties *viz.*, V-16, V-70, TVX-944, V-37, V-188 and V-240 recorded longer latent period compared to the fast rusting varieties C-152 and HG-171. Reddy and Khare (1988) reported that, resistant varieties of groundnut to *P. arachidis* had longer incubation period, lower pustule densities and smaller pustules than susceptible ones. Habtu and Zadoks (1995) and Hegde (2001) reported that, latent period extended from 9.4 to 18.6 days and 9.17 to 16.22 days in resistant genotypes of bean and soybean, respectively.

Pustule density, size and number of spores per pustule

Amount of inoculum in nature determines the course of epidemic of any disease. In case of rusts, uredospores which were responsible for development of disease, determine the rust epidemics. Therefore, number of uredospores produced in each pustule, pustule size and pustule numbers on leaves were most important in determining the resistance of varieties. Reduced number of uredospores per pustule in some genotypes has been considered as an important component of slow rusting (Sharma *et al.,* 1986). Differences in pustule number among cultivars were found in most patho-systems as reported by Groth and Urs (1982) and Statler and McVey (1987). The importance of pustule size as an index of slow rust resistance was reported by Webster and Ainsworth (1988) and Habtu and Zadoks (1995).

The slow rusting phenomena and components were studied in 13 cowpea cultivars against rust. The study indicated that latent period, number of pustules per cm^2 and size of the pustule were the important components of slow rusting resistance in cowpea. Varieties *viz.*, V-16, V-70, TVX-944, V-37, V-118 and V-240 have recorded longer latent period, lesser number of pustules per cm^2 of leaf area, smaller pustule size and lesser number of uredospores per pustule, but the reverse trend was observed in fast rusting varieties C-152, HG-171 and in intermediates NPRC-1 and NPRC-3 (Chandramouli, 1992; Groth and Urs, 1982). Reddy and Khare (1988) studied the components of resistance in groundnut varieties to *P. arachidis* in the greenhouse involving six cultivars differing in susceptibility and reported that, resistant varieties had longer incubation periods, lower pustule densities and smaller pustules than susceptible ones.

DISEASE MANAGEMENT

Fungicides

Use of fungicides is an alternate method of managing the rust of groundnut in the absence of resistant cultivars or when there is outbreak of disease. Several reports are available on the use of fungicides for the management of groundnut rust.

Hammons (1977) reported that, weekly application of chlorothalonil fungicide has the greatest efficacy against rust of groundnut. Smith and Littrell (1980) reported that chlorothalonil was one of the most extensively used fungicide and was effective against leaf spots and rust.

Kalekar *et al.* (1985) reported that, chlorothalonil performed best among 16 fungicides tested and increased the yields upto 100 per cent. Subrahmanyam *et al.* (1990) reported that, hexaconazole gave the best control

of rust and late leaf spot of groundnut. Jadeja *et al.* (1999) studied the efficacy of triazoles and reported that, best control was achieved with three sprays of hexaconazole and difenconazole and these treatments also gave more pod and fodder yield. The hexaconazole treated plots gave a higher pod and fodder yield and also highest net returns. Best control of rust and late leaf spot was reported by hexaconazole (Subrahmanyam *et al.*, 1990). While, Benagi (1991) reported that, groundnut rust can be controlled effectively by spraying with propiconazole with higher pod and haulm yield.

Botanicals

Plant derivatives possessing pesticidal properties are evoking worldwide interest as an alternatives or as supplements for the existing pesticides for several reasons (Toriyama, 1972). Integration of chemicals, plant extracts, biotic agents along with resistance for managing plant disease has been considered as a novel approach (Papavizas, 1973). Jones *et al.* (1989) reported chemical nature of neem products as fungi toxicants. Usman *et al.* (1991) found that, neem seed kernal extract (2%) was most effective in controlling rust of groundnut. Spraying of neem leaf extract (2%) in combination with recommended fungicides recorded numerical superiority in reducing rust incidence in groundnut (Shivashankar and Kadam, 1993).

Benagi (1995) revealed that, Chlorothalonil application on 30th and 50th day after sowing and either Tridax leaf extract or neem seed kernel extract (5%) spray on 45 DAS gave better pod yield with minimum disease severity. Patil (1996) reported that, the addition of Neem kernel and/or Amaranthus leaf extract in the spray schedule along with propiconazole were found to be effective in reducing the per cent disease index at all the stages of crop growth.

MATERIAL AND METHODS

III MATERIAL AND METHODS

Present investigations were carried out both in the laboratory and field during 2002-03 and 2003-04. Laboratory, glasshouse and all the field experiments were carried out in the Regional Agricultural Research Station, Raichur, University of Agricultural Sciences, Dharwad, Karnataka, while some laboratory and glasshouse experiments were undertaken at Department of Plant Pathology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka.

Raichur is situated in the north eastern dry zone of Karnataka state (zone 1) at16°15' N latitude and 77°20' E longitude at an altitude of 389 m above mean sea level. It has a tropical rainy climate with a mean annual precipitation of about 687 mm, unevenly distributed over a period of seven to eight months (April-November) with one prominent peak in July. Temperature ranges from 11-37°C, while December to January are the coldest months (11-22°C). The relative humidity fluctuates between 40 to 85 per cent. The meteorological data recorded during the experimental period at Raichur are presented in Appendix-I and II.

The details of materials used and the methodology adopted during the course of this investigation are described here under.

DISEASE SURVEY AND SURVEILLANCE

Survey for the severity of rust on groundnut

Groundnut is one of the main *kharif* crops of northern Karnataka which is grown both under rainfed and irrigated conditions. The most commonly grown varieties of groundnut in these areas are *viz.*, TMV-2, KRG-1, R-8808, R-9251 and more recently GPBD-4. A fixed plot survey was carried out in the area to know the incidence and severity of rust during *kharif* 2002 and 2003.

Farmers fields in different villages of Deodurga, Sindhanur, Lingasgur, Manvi and Raichur of Raichur district; Gangavati, Koppal, Kushtagi and Yelburga taluks of Koppal district; Bhalki and Bidar taluks of Bidar district; Aland, Gulbarga, Shahapur and Shorapur taluks of Gulbarga district; Bagalkot and Hungund taluks of Bagalkot district, Gadag taluk of Gadag district; Dharwad and Hubli taluks of Dharwad district, Bijapur and Muddebihal taluks of Bijapur district, Haveri taluk of Haveri district; Siruguppa, Hospet and Bellary taluks of Bellary district and Gokak taluk of Belgaum district were covered under survey programme. In each village, five groundnut fields were selected randomly on both sides of the road and 65 to 85 days old groundnut crops were observed for rust incidence. In each field, ten groundnut plants were randomly selected and per cent disease index of rust was recorded by following 1-9 point modified scale developed by Subba Rao *et al* (1990), as given here under (Plate 2a, 2b and 2c).

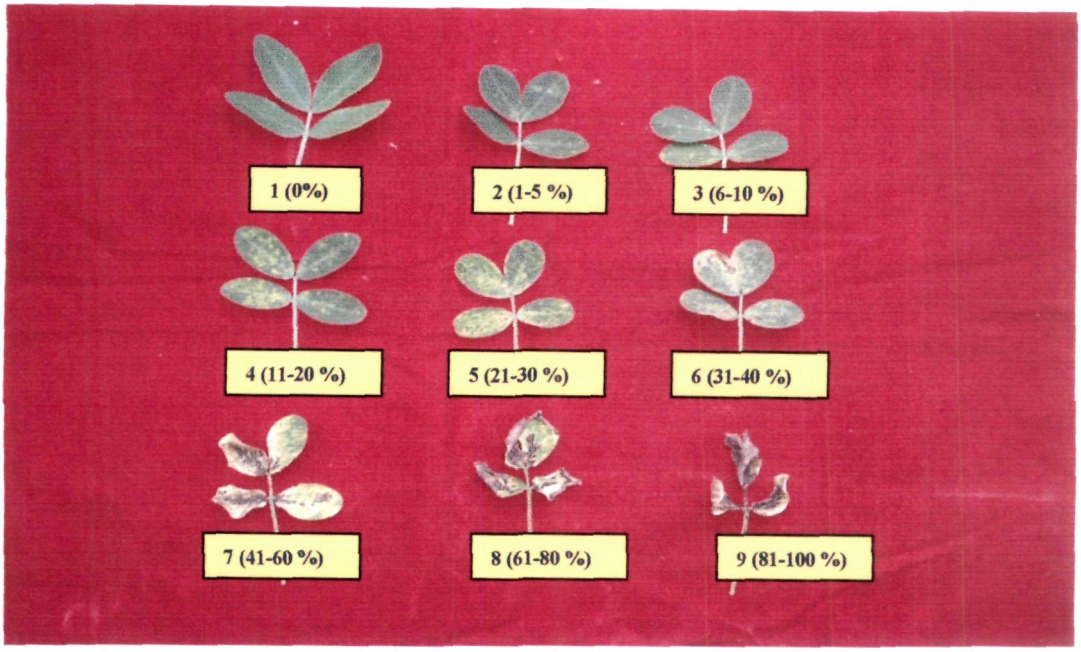

Plate 2a. Modified 9-point scale for field evaluation of rust in groundnut (Adaxial surface)

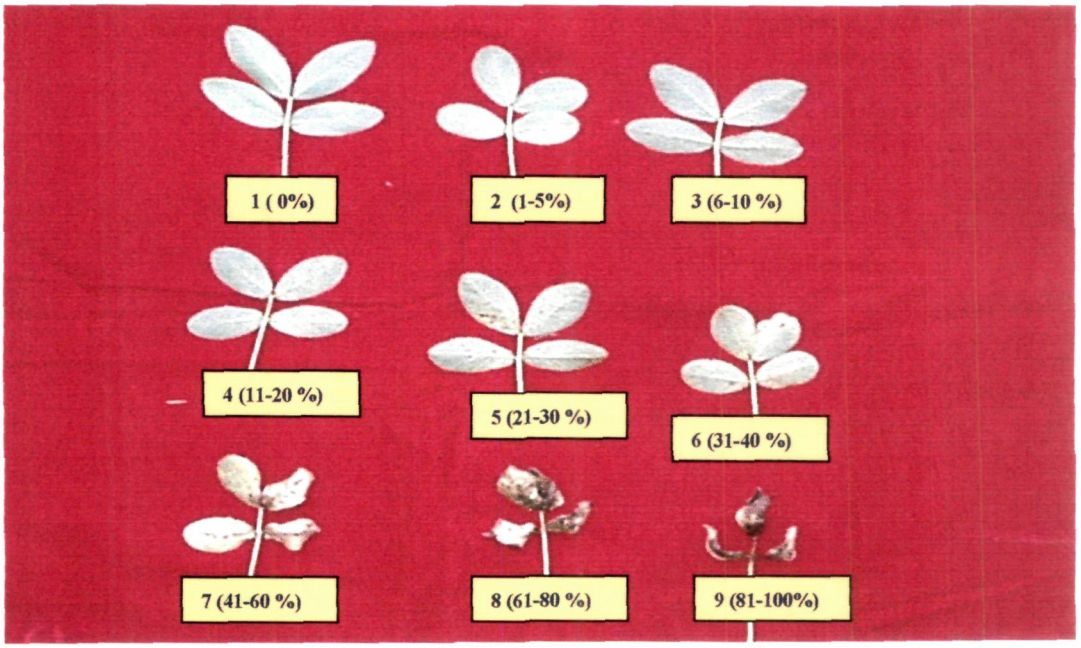

Plate 2b. Modified 9-point scale for field evaluation of rust in groundnut (Abaxial surface).

Plate 2c. Modified 9-point scale for field evaluation of rust in groundnut (Adaxial & Abaxial surface)

Recording of rust severity

Rating value	Description	Disease severity
1.	No disease.	0
2.	Pustules sparsely distributed, largely on lower leaves.	1-5
3.	Many pustules on lower leaves, necrosis evident; very few pustules on middle leaves.	6-10
4.	Numerous pustules on lower and middle leaves; severe necrosis on lower leaves.	11-20
5.	Severe necrosis on lower and middle leaves; pustules may be present on top leaves, but less severe.	21-30
6.	Extensive damage to lower leaves; middle leaves necrotic, with dense distribution of pustules; pustules on top leaves.	31-40
7.	Severe damage to lower and middle leaves; pustules densely distributed on top leaves, which are severely necrotic.	41-60
8.	10 per cent damage to lower and middle leaves; pustules on top leaves, which are severely necrotic.	61-80
9.	Almost all leaves withered; bare stems seen.	81-100

Further these scales were converted to Per cent Disease Index (PDI) using formula given by Wheeler (1969).

$$PDI = \frac{\text{Sum of numerical values}}{\text{Number of leaves observed}} \times \frac{100}{\text{Maximum disease rating}}$$

Mapping of groundnut endemic areas in northern Karnataka

Based on the severity, the disease incidence has been categorised as follows.

0-25% - Light infection.

26-50% - Moderate infection.

51-75% - Severe infection.

76 – 100% - Very severe infection.

ASSESSMENT OF LOSS DUE TO GROUNDNUT RUST

A field experiment was conducted during *kharif* 2002 and 2003 at Regional Agricultural Research Station (RARS), Raichur to find out the number of sprays of hexaconazole 5% EC required to manage rust in susceptible (KRG-1) and moderately resistant (K-134) varieties and to assess the influence of hexaconazole sprays on pod and haulm yields. Six treatments were imposed with 0.1 per cent hexaconazole besides a treatment with unsprayed control. The spray schedule was started on 40 DAS, irrespective of the disease appearance. The details of the treatments are furnished below.

Sl. No.	Treatment	Spray schedule
1.	T1	One spray (at 40 days after sowing)
2	T2	Two sprays (at 40 and 47 DAS)
3	T3	Three sprays (at 40,47 and 54 DAS)
4	T4	Four sprays (at 40, 47,54 and 61DAS)
5	T5	Five sprays (at 40, 47, 54,61 and 68DAS)
6	T6	Six sprays (at 40, 47, 54, 61,68 and 75DAS)
7	T7	No spray (without fungicidal application)

Experimental details

Design	:	Randomized Block Design	
Plot size	:	5 x 3 m^2	
Varieties	:	KRG-1 and K-134	
Season	:	*Kharif*	
Year	:	**2002**	**2003**
Date of sowing	:	20.06.2002	18.06.2003
Date of I spray	:	30.07.2002	28.07.2003
Date of II spray	:	6.08.2002	4.08.2003
Date of III spray	:	13.08.2002	11.08.2003
Date of IV spray	:	20.08.2002	18.08.2003
Date of V spray	:	27.08.2002	25.08.2003
Date of VI spray	:	3.09.2002	1.09.2003

The disease (PDI) was recorded at different stages of crop growth *viz.*, 47, 54, 61, 68, 75 and 82 DAS. Carbendazim (0.1%) was sprayed thrice at 40, 55 and 70 DAS in order to prevent the infection of leaf spots. Besides, the crop was also sprayed with sorghum leaf extract (10%) + monocrotophos (0.1%) twice at 20 and 30 DAS to manage peanut bud necrosis disease.

Observations recorded

a) Per cent disease index (PDI)

The intensity of the disease was recorded by scoring all the individual ten plants in each treatment using 1-9 scale (Subba Rao *et al.*, 1990). Further, the PDI was calculated with the above scales using the formula given by Wheeler (1969).

b) Yield

Crop was harvested after maturity of the pods and, pod and haulm yields of net plot were recorded (kg/ha) and later expressed in q/ha.

c) Per cent reduction over control

$$\text{Disease reduction (\%)} = \frac{\text{Disease severity in control} - \text{Disease severity in treatment}}{\text{Disease severity in control}} \times 100$$

d) Per cent yield increase over control

$$\text{Yield increase (\%)} = \frac{\text{Yield in treatment plot} - \text{Yield in control plot}}{\text{Yield in control plot}} \times 100$$

e) Per cent loss in pod and haulm yield

The per cent loss in pod and haulm yield was calculated by using following formula.

$$\text{Per cent yield loss} = \frac{Yp - Yx}{Yp} \times 100$$

Where,

Yp= Potential yield

Yx = Yield when per cent disease severity is x

f) Benefit Cost Ratio (BCR)

Total cost incurred for application of fungicides including cost of fungicides and labour was calculated. Additional benefit due to increased yield in each treatment over control was also worked out and benefit cost ratio was calculated using additional benefits and total costs.

Crop loss model

An attempt was made to identify the relationship between yield and level of incidence of disease in the form of PDI taking observations on disease at weekly intervals starting from 47 to 82 DAS of the crop.

Crop loss models for rust of groundnut were developed using simple linear regression functions in the form Y = a + bX with Y as yield in quintals and X as per cent disease index. The models were developed for two different varieties *viz.*, KRG-1 and K-134 for two consecutive years 2002 and 2003. The square of the correlation coefficient (r) known as coefficient of determination (R^2) was calculated to know the extent to which the model is capable of explaining the relation between the yield and the PDI.

EPIDEMIOLOGICAL STUDIES

Viability and survival of uredospores of *P. arachidis*

The present investigation on viability and survival of uredospores of *P. arachidis* was undertaken as a part of epidemiological study during 2002-2003 in the glasshouse of RARS, Raichur. This gives some idea about the perpetuation of the disease during the off season. The freshly harvested rust infected leaves of groundnut plant were collected and stored under different storage conditions *viz.*, deep freeze (-5°C), freeze (4-5°C), under tree shade (15-20°C), room temperature (20-25°C), glasshouse (25-28°C) and field condition (28-30°C) in separate lots.

Initial count on per cent germination of uredospores on each type of leaf was recorded before preserving the samples. The viability of uredospores

each type of leaves under different storage conditions was regularly examined by checking germination under microscope.

Self sown/voluntary groundnut plants

Survey was conducted during 2002 and 2003 (Post harvest period of groundnut crop) to search for self sown/voluntary grown groundnut plants in groundnut cultivating areas to find out the possibility of survival of uredospores of *P. arachidis* during off season.

Search for telial stage of *P. arachidis*

An effort was made to locate the telial stage of *P. arachidis* during 2002-2003. The rust samples from infected leaves, stems and petioles and also fresh and dried infected plant parts from fodder were collected from different places of northern Karnataka and preserved at low temperature and also at higher temperature. The suspension was prepared from all the collected samples and observed critically under compound microscope for the presence of teliospores

Effect of temperature levels on germination of uredospores

Freshly collected matured and viable uredospores of *P. arachidis* were dispersed in sterile deionised water by vigorous shaking. Spore concentration was so adjusted that 30 to 40 uredospores per microscopic field under low power were maintained. Spore suspension drops were placed on a clean glass slide in a moist chamber prepared by lining the insides of a larger Petridish (15 cm) with moist blotting papers and incubated. Per cent germination of hundred spores was recorded after 24 hours of incubation. The temperature levels selected for study were *viz.*, 5, 10, 15, 20, 25, 30, 35 and 40°C. Four

replications for each treatment were maintained and their influences was studied.

Effect of incubation period on germination of uredospores

Uredospores of *P. arachidis* were collected first by scraping the surface of pustules with clean stainless needle. The uredospores were collected from susceptible variety KRG-1 and uniform suspension of uredospores was prepared in tap water. The suspension was sprinkled on clean glass slides kept in the Petridish lined with moist blotting paper and then incubated at room temperature (24±1°C) at different time intervals. The per cent germination of uredospores was recorded after 4, 8, 12, 24, 48 and 72 hours of incubation. Proper care was taken to see that, not more than 10-15 minutes were lapsed between preparation of suspension and incubation. On each slide, three drops of suspension were placed and they were replicated four times. The number of uredospores germinated were recorded and then per cent germination was worked out by observing 500 uredospores in each replication.

Effect of humidity in relation to disease development

An experiment to study the effect of humidity on development of rust disease was carried out in the glass house of RARS, Raichur during *kharif*, 2003. The plants of susceptible groundnut variety, KRG-1 were raised in 50x30 cm earthen pots with four replications. Four plants were maintained per pot. The fresh uredospore inoculum collected from the highly susceptible variety KRG-1 was inoculated on 35 days old plants by stapler method of inoculation. The plants were covered with transparent polythene bags and

kept for incubation to provide maximum humidity. The bags were removed at an interval of 6, 12, 24, 48 and 72 hours. The plants were scored for intensity of pustules and per cent disease index at 20 days after appearance of first symptom.

Effect of plant age in relation to infection of *P. arachidis*

Similar methodology as stated in the study of humidity in relation to disease development was adopted. The experiment was conducted to identify the susceptible stage of the crop. The inoculation was made on plants of 10, 20, 30, 40, 50, 60, 70, 80 and 90 days old with four replications. Observations on disease severity was recorded using 1-9 scale after 20 days of appearance of first symptom and then per cent disease index was estimated.

Effect of date of sowing on the incidence of rust

A field experiment was conducted during *kharif* 2002 and 2003 at Regional Agricultural Research Station, Raichur, Karnataka to find out the best sowing date for least incidence of rust. The experiment was conducted with randomized block design with three replications. The first sowing date treatment was imposed by sowing seeds of highly susceptible variety, KRG-1 on 1st June and subsequent sowings were done at an interval of 15 days till the last sowing date on 1st September. The observations on per cent disease index (PDI), yield of pod and fodder were recorded as explained in crop loss assessment trial.

Aerobiology

As a part of epidemiology of disease, aerobiological studies such as trapping of uredospores, first appearance uredospore load and disease, and development of spore load and progress of disease were carried out during 2002 and 2003.

Trap nursery trial

A trap nursery consisting of six varieties *viz.,* JL-24, DH-86, R-8808, GPBD-4, K-134 and DH-53 were planted during *kharif* 2002 and 2003 at Regional Agricultural Research Station (RARS), Raichur, Agricultural Research Station (ARS), Gulbarga; ARS, Gangavati; RARS, Bijapur; ARS, Hagari; ARS, Bidar; ARS, Annigeri; Main Agricultural Research Station (MARS), Dharwad and ARS, Arabhavi to record the occurrence of disease caused by *P. arachidis.*

To trap the uredospores of *P. arachidis* during *kharif* 2002 and 2003, aeroscope for exposure of stationary slides was mounted at a height of 1.5 m during the cropping seasons in the field of RARS, Raichur from 14-05-2002/03 to 9-12-2002/03. The slides were smeared with a thin layer of vaseline and used for trapping the uredospores. The slides were removed every day at 08.30 h. Average number of uredospores per microscopic field were recorded under low power objective (10x) by taking count of ten microscopic fields in each slide.

Appearance of disease on groundnut crop in the aeroscope installed field was recorded. Observations were made daily to record the first appearance of the disease in the field. In addition, the incidence of disease

was also recorded at weekly intervals starting from first appearance. Meanwhile, the weather data *viz.*, maximum and minimum temperatures, morning and evening relative humidity and rainfall received during the period of aerobiological studies were also recorded (Appendix I and II).

Possible pathway of *P. arachidis*

Based on the data collected pertaining to appearance of disease in trap nurseries at different locations during 2002 and 2003, possible pathway of movement of uredospores of *P. arachidis* was traced.

Effect of weather parameters on spore load and incidence of disease

An attempt was made to study the effect of weather factors in relation to spore load and disease incidence by subjecting the data to regression analysis. The weather parameters were correlated to weekly spore load and weekly per cent disease index by calculating the Karl Pearson's correlation coefficient (r), as given below

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2 \sum_{i=1}^{n} (Y_i - \bar{Y})^2}}$$

Where x and y are two variables

$\bar{X}$ → Mean of X
$\bar{Y}$ → Mean of Y
r → Karl Pearson's Correlation coefficient.

Further, the data was subjected to step down multiple linear regression analysis to find out the linearity of the independent variables for prediction.

Disease prediction models

The weekly disease severity was graphically analysed for estimation of disease development and to predict the intensity. The suitable models using logistic method were developed to estimate the disease progression.

$$\hat{Y}_t = K_1 + \frac{K_2}{1+e^{a+bt}}$$

Where,

$\hat{Y}_t$ = Expected severity at time t and t = Time interval in seven days.

K_1, K_2, a and b are constants. K_1 and K_2 are known as upper asymptotes of the logistic curve. In case of rust development K_1=0 and K_2=100 per cent severity. The values of a and b were calculated by the method of least squares (Cox and Hinkley, 1979 and Snedecor and Cochran, 1994).

STANDARDIZATION OF INOCULATION TECHNIQUES

The study was undertaken to find out comparative efficacy of different inoculation techniques to create high disease pressure, maintenance and multiplication of inoculum and also to study slow rusting mechanism. The experiment was carried out in the glasshouse of RARS, Raichur by using a susceptible variety KRG-1. The plants were raised in glasshouse and were inoculated at 35 days after sowing (DAS) in the evening hours by different methods as detailed below.

a) Spray inoculation : The uredospore suspension containing 100-150 spores per microscopic field under low power (10x) in distilled water was used for inoculation by spraying with a hand sprayer.

b) Dusting : Leaves of groundnut plant were first moistened by sprinkling water and then fresh uredospores were dusted on them by tapping matured viable uredospores from infected leaves on healthy leaves.

c) Stapler method : The uniformly rust infected groundnut leaves were collected from the fields and stapled on healthy groundnut leaves in such a way that the ventral surface of the diseased leaf touching the ventral surface of the healthy one. Before stapling, lower surface of both leaves were moistened with distilled water.

d) Leaf dip inoculation : The uredospore suspension containing 100-150 spores per microscopic field under low power (10x) was prepared in distilled water and the leaves of groundnut plants grown in glass house were dipped in spore suspension so that, uredospores adhere to the leaves.

e) Cotton swabbing : Absorbent cotton plug was dipped in the freshly prepared uredospore suspension prepared with distilled water in Petridish and then swabbed gently on both the surfaces of the groundnut leaves.

f) Needle inoculation : Uredospores were picked from infected leaves by wet arrow head of inoculation needle and applied on healthy leaves by rolling the needle then followed by a fine spray of water.

g) Carborandom application + dusting : A pinch of carborandom (600 mesh) was sprinkled on lower surface of leaf following a fine spray of water and then smeared with cotton plug dipped in uredospore suspension.

h) Control : Water spray alone.

All the above said treatments were replicated thrice and the inoculated plants were covered with polythene bag for 24 hours. The inoculated plants in

all the methods were kept under observation. Number of days taken for first appearance of disease (latent period) and per cent disease index (PDI) at pod development stage were calculated.

HISTOLOGICAL AND HISTOCHEMICAL STUDIES

This study was attempted to understand the histological and histochemical changes that occur due to the infection of groundnut leaves of healthy and diseased leaves.

Sampling:

The leaves were sampled randomly from healthy and infected plants of different varieties and they were washed thoroughly in tap water to remove all the dusts present on them before fixing.

Fixation

The leaves collected were cut into pieces of 2.0 cm length and fixed in standard formalin acetic acid fixative (FAA – 90 ml 70% ethyl alcohol, 5 ml acetic acid and 5 ml formalin). It was kept as such for 24 h. for proper killing and fixing.

Dehydration

Fixed samples were washed thoroughly with 70 per cent alcohol and dehydrated using ethanol (80%, 90% and absolute alcohol, respectively) and n-butanol in combination with alcohol in the ratio of 1:3, 1:1, 3:1 and absolute n-butanol leaving the material in each grade for a period of one and 0.5 to 2 h.

Infiltration and embedding

Paraffin with 60° C melting point was used for infiltration and added successively to the medium of pure n-butanol containing dehydrated samples

until the medium reached a saturation point at room temperature. The samples were kept in an oven maintained at 60°C. Subsequent changes with fresh molten paraffin were given at every 24 h. interval to replace even the least traces of butanol with paraffin. The material was further embedded in paraffin wax (58-60° C melting point) employing paper boat technique (Jensen; 1962). The paper boat was coated priorly with glycerine.

Microtoming and affixing the sections

Uniformly thin sections of 12 µm thickness were cut with the ERMA rotatory microtome. An adhesive was prepared with 1.50 g per 100 ml of distilled water and 0.50 g. of potassium dichromate was added to prevent the fungal growth. A few drops of gelatin were poured on the surface of a pre cleaned microslide with the help of blade placed on the adhesive surface. The slides were then warmed over a hot plate maintained at 45° C for 1-2 min to facilitate flattening and stretching of the ribbon. The excess adhesive was drained on to blotting paper and then slides were later dried for 24 h at room temperature.

Deparaffinizing and hydrating sections

The sections were deparaffinized using xylene. These sections were treated with different grades of alcohol for gradual dehydration. Later, sections were subjected to structural and cytochemical staining directly or after hydration depending on the requirement. The following steps were followed for deparaffinizing and after each step, the slides were blotted to remove the excess chemical adhering to slides.

Pure xylene	5 min.
Xylene + Absolute alcohol	5 min.
Absolute alcohol	5 min.
90 per cent alcohol	5 min.
70 per cent alcohol	5 min.
50 per cent alcohol	5 min.
Water	5 min.

Staining, dehydration and mounting the slides

After blotting, the sections were subjected to histological and histochemical staining for localization of different cellular chemical compounds namely insoluble polysaccharides, proteins and the nucleic acids. The different histochemical stains along with their colour indication as to the corresponding metabolites are presented in the Table. 26. The sections were then dehydrated subsequently using different grades of alcohol and finally passed through xylene and mounted in DPX. The steps followed are as follows.

Staining	**Time**
Dehydration alcohol series	
Rince in tap water	Up to 15 min.
50 per cent alcohol	5 min.
70 per cent alcohol	5 min.
90 per cent alcohol	5 min.
Absolute alcohol	5 min.
Xylene	5 min.

Structural staining

To see the anatomical changes in the leaf of healthy and diseased plants, the sections were passed through safranine and fast green stains. Steps followed for structural staining were,

1. Staining in 1 per cent safranine (1 g of safranine in 100 ml of 50 per cent alcohol) for 2 h.
2. Dehydrating the sections in 50, 70 and 90 per cent alcohol for 5 min.
3. Staining with 0.5 per cent fast green (0.5 g of fast green in 100 ml of 95 per cent alcohol) for 5 min.
4. Dehydrating with 95 per cent absolute alcohol for 5 min. each.
5. Cleaning in xylene and mount in DPX.

Histochemical staining

Insoluble polysaccharides

Localisation and assessment of total insoluble polysaccharides , protein and nucleic acid was done by employing periodic acid Schiff's (PAS) method (Hatchkiss, 1948), Mercuric bromophenol blue (MBB) method (Maiza *et al.*, 1953) and Azure B method (Flax and Himes, 1952).

Histochemical assessment

Based on visual observations of the degree of histochemical reactions with specific reagents for various cellular compounds of the leaves, the qualitative grading was done as detailed below.

Rich : + + + Medium : + +

Low : + Absent/Negligible : --

MECHANISM OF RESISTANCE

Resistance mechanism on the basis of histological parameters and biochemical changes with respect to sugars, phenol and protein content in resistant, moderately resistant and susceptible varieties of groundnut were studied. For this study, resistant varieties *viz.*, GPBD-4 and DH-22; moderately resistant varieties *viz.*, K-134 and R-8808 and susceptible varieties *viz.*, KRG-1 and TMV-2 were selected.

Physiological basis of resistance

Histological parameters

Different histological parameters *viz.*, cuticular thickness, epidermal cell thickness, number of epidermal cells, number and size of stomata in different genotypes were studied. The study was carried out as per the procedure explained by Varadarajan and Wilson (1973).

Epicuticular Wax

The wax content was determined by the method of Ebercon *et al.* (1977). This method is based on the colour change produced by the reaction of wax with acidic potassium dichromate.

Biochemical basis of resistance

Extraction of leaf material in alcohol

Estimation of metabolities requires their complete extraction from the tissues. The activities of the enzymes which synthesize and utilize them need to be stopped at once to get reliable values. Plant constituents possess different solvents. Though water is the universal solvent, it does not penetrate tissues quickly enough to stop enzymatic activity. In this context alcohol especially hot alcohol, is the best solvent for the extraction. The

leaf material was extracted as per the procedure given by Jaypal and Mahadevan (1968).

Estimation of biochemicals

The reducing sugar was estimated by following Nelson's modification of Somogyi's method (Nelson, 1944). Non reducing sugars were hydrolysed using 1 ml 1N H_2SO_4 and then estimated as in case of reducing sugars to get the total sugars. Non reducing sugars were calculated by subtracting the reducing sugars from that of total sugars. The estimation of total phenols and orthodihydroxy phenol present in plant samples was done by following Folin-Ciocalteau Reagent method and Arnow's Reagent method respectively. While, estimation of protein content in samples was done as per the procedure given by Lawry *et al.*(1951). Bovine serum albumin was used as the standard.

STUDIES ON VARIABILITY IN *P. arachidis*

Studies on variability of *P. arachidis* has greater significance in breeding for disease resistance. Hence, variation in morphology of pustule and uredospores of different isolates of *P. arachidis* and their reaction on selected host differentials were studied in the present investigation.

Collection of rust samples

Twenty three rust samples were collected and used for studying variability in *P. arachidis*. The samples were collected from different places of Karnataka state and places from other states also. The details of cultivar, location, crop stage, name of the isolate etc was presented (Table a).

Preservation of samples

After receiving the samples from different sources, they were kept in freeze in small plastic box with proper labeling. The samples were then

Table a. Details of cultivar, location, crop stage, name of the isolate used for studying variability in *P. arachidis*

Name of the isolate	Location	Variety	Stage of the crop	Type of cultivation
A. Karnataka				
Annigeri	Annigeri	Local	Pod formation	Rainfed
Arabhavi	Arabhavi	KRG-1	Peg formation	Irrigated
Bagalkot	Bagalkot	TMV-2	Pod development	Irrigated
Bellary	Bellary	TMV-2	Maturity stage	Irrigated
Bheemarayanagudi	B.Gudi	KRG-1	Pod formation	Irrigated
Bidar	Bidar	TMV-2	Pod development	Rainfed
Bijapur	Bijapur	TMV-2	Pod formation	Rainfed
Gangavati	Gangavati	S-206	Pod development	Irrigated
Gulbarga	Gulbarga	TMV-2	Pod development	Rainfed
Raichur	Raichur	TMV-2	Pod formation	Irrigated
Siruguppa	Siruguppa	TMV-2	Pod development	Irrigated
C. Maharashtra				
Akola	Akola	--	Pod formation	Irrigated
Digraj	Digraj	--	Pod development	Rainfed
Jalgaon	Jalgaon	--	Pod formation	Irrigated
Latur	Latur	JL-24	Pod formation	Rainfed
Mumbai	Mumbai	--	Maturity stage	Irrigated
D. Gujarat				
Junagadh	Junagadh	--	Pod development	Rainfed
E. Tamil Nadu				
Aliyarnagar	Aliyarnagar	--	Pod development	Irrigated
Coimbatore	Coimbatore	--	Pod formation	Irrigated
F. Andhra Pradesh				
Jagtial	Jagtial	--	Pod development	Irrigated
Tirupati	Tirupati	--	Pod formation	Irrigated
F. Madhya Pradesh				
Khargone	Khargone	--	Pod development	Rainfed

maintained on seedlings of susceptible variety KRG-1 under glass house conditions. Further, the inoculum of different isolates was used for studying variability.

Raising plants for inoculation

The plants of KRG-1 were grown in seedling room where no rust material was kept or in a spore proof room in glasshouse and 15 days old seedlings were used for inoculation.

Inoculation

Spore suspension was prepared in small cavity dish with water and the plants were inoculated by spray inoculation with inoculum. After 12 h exposure to high humidity moist chamber, the plants were transferred to cages specially designed for maintaining rust cultures in the glass house.

Isolation of single pustule isolation

The isolates collected from different places were spray inoculated on the seedlings of KRG-1 grown under glasshouse. The uredospores from a single pustule developed on KRG-1 plants were stapler inoculated on the true expanded leaves of another fresh healthy KRG-1 seedling. After establishing the inoculum by single pustule, the same was maintained and they were named.

Maintenance and multiplication of inoculum

The inoculum of all the isolates of *P. arachidis* was maintained and multiplied in isolation on seedlings of KRG-1 variety in the glasshouse by following spray inoculation method.

Morphological characters

Observations on shape of pustule of different isolates maintained on KRG-1 plants was recorded. Further, the size of pustule was measured as

per the procedure explained in slow rusting mechanism. The colour of uredospore under microscope was also recorded and the size of uredospore was measured with stage and ocular micrometer by taking 10 uredospores of each isolate and mean was calculated.

Evaluation of standard host differentials

While studying the genotypes for resistance against rust during the past years from germplasm, some genotypes/entries showed difference in their resistance *viz.*, resistant, moderately resistant and susceptible indicating different degree of resistance and susceptibility to the rust cultures. On the basis of disease reaction, initially 40 genotypes/entries from germplasm were selected. After repeated and rigorous screening against the Raichur rust culture, only genotypes containing released genotypes and test entries were selected which showed consistent reaction to the rust culture and others were deleted. A set of seven genotypes *viz.*, Dh-22 (Tan), Dh-22 (Red), Dh-53, ICGV-91116, R-9227, R-2001-1 and JL-24 were fixed as proposed set of differential hosts for studying variability of *P. arachidis*.

Inoculation of differential set

Seeds of all the differentials were sown in 14 x 12 cm size earthen pots on 17-09-2003. Three seedlings were maintained in each pot. The fresh uredospores of each isolate was spray inoculated using a small automizer when the first pair of true leaves were fully opened. Thus inoculated seedlings were covered with thin polythene bag for 24 hours and then transferred to glass house. All the rust cultures were inoculated to proposed differentials.

Assessment for virulence

Rust reactions on differential lines were evaluated 20 days after inoculation. The evaluation was based on development of disease *viz.*, 'Infection' (+) and 'No infection' (–).

SLOW RUSTING MECHANISMS IN GROUNDNUT GENOTYPES

An experiment to study slow rusting mechanisms was carried out in the field of Oilseed Block, RARS, Raichur during *kharif* 2003. Twenty one genotypes were tested for slow rusting characters.

Each genotype was sown in 50X30 cm. cement pots with three replications. Four plants were maintained per pot. The fresh uredospore inoculum collected from the highly susceptible cultivar KRG-1 was inoculated at 40 DAS by stapler method. The plants were covered with transparent polythene bags for 24 h. The variation in temperature in the glasshouse ranged from 20-28°C.

The details on the observations of the slow rusting components are furnished below.

1) Latent period

It was calculated as the time in days between the days of inoculation and the time at which the first visible pustule appeared (Parlevliet, 1975).

2) Pustule number

Number of pustules on infected leaf per sq. cm. was recorded using cardboard label having 1 sq. cm. open windows. The window was placed on five randomly selected places on ventral surface of the leaf while the care was taken to avoid the midrib portion. The observations were recorded for each

genotype from upper, middle and lower sample leaves (Habtu and Zadoks, 1995).

3) Pustule size (PS)

This parameter was recorded at pod development stage. Six pustules from each sample leaflet were selected on a random basis for each genotype. Length (a) and breadth (b) of the pustule was measured with the help of a projection microscope. The area of the pustule was calculated as follows (Kochman and Brown, 1975).

$$PS = \Pi (a \times b) \times \frac{1}{4}$$

4) Uredospores/Pustule

With the help of a clean needle the spores were collected in 0.5 ml distilled water in watch glass. The spore suspension thus obtained was stirred uniformly with the help of a glass rod after adding a drop of Tween-20 to the suspension to remove clumped spores if any. A drop of spore suspension was taken on haemocytometer and cover slip was placed on it and observed under microscope. The number of spores/pustule was calculated as follows (Rice,1939).

$$N = X \ (500 / 0.85) \ X^2$$

where, X = No. of spores per mm^2 ; 0.85 = The correlation factor indicating 85% of spores were dislodged from the pustule

5. Per cent disease index

The disease severity were recorded at 47, 54, 61, 68, 75 and 82 DAS as per 1-9 point modified scale as mentioned in loss assessment trial. Further,

these scales were converted to per cent disease index (PDI) using formula given by Wheeler (1969).

6. Rate of infection (r)

Per cent disease indices calculated at seven days interval for each genotype was used to calculate 'r' by using the following formula (Vander Plank, 1963).

$$\text{'r' per day} = \frac{2.3}{(t_2-t_1)} \log \frac{X2}{X_1}$$

Where X_1 = PDI at t_1 date ; X_2 = PDI at t_2 date

$t_2 - t_1$ = Time interval in days between two observations

7. Area under disease progress curve (AUDPC)

PDI Calculated at weekly interval for each genotype was used as severity of the disease and AUDPC as calculated using the following formula (Wilcoxon *et al.*, 1975).

$$AUDPC = \sum_{i=1}^{k} (S_i-S_{i-1})/2)d$$

Where, S_i = Rust severity at different weeks ; K = Number of successive evaluations of rust ; d = Interval between two evaluations i and i-1 evaluations of disease.

COST EFFECTIVE INTEGRATED DISEASE MANAGEMENT

A field trial on integrated disease management was carried out at Regional Agricultural Research Station, Raichur during *kharif* 2002 and 2003 under irrigated conditions to know the efficacy of four fungicides *viz.*, hexaconazole (H), propiconazole (P), difenconazole (D), chlorothalonil (C) and

a botanical pesticide Neemseed kernel extract (N) against groundnut rust disease.

Preparation of Neemseed kernel extract (NSKE)

The dried Neem seed kernels were taken and washed thoroughly and air dried. Known quantity of kernels were weighed and soaked in water for 24h. Then, the kernels were crushed with the grinder and the extract was filtered serially twice in muslin cloth and made 5 per cent w/v basis. Four ml of spreader (Teepol Ag) was added per 18 lit of spraying solution. In each replication one control plot without fungicidal application was maintained. The chemicals were measured accurately just before spraying and mixed thoroughly with water. The details of the treatment combinations are given here under.

Experimental details

Sl.No.	Treatment	Concentration (%)
1	C - C - C	0.2 - 0.2 - 0.2
2	N - N - N	5.0 – 5.0 – 5.0
3	H - H - H	0.1 - 0.1 - 0.1
4	P - P - P	0.1 - 0.1 - 0.1
5	D - D - D	0.1 - 0.1 - 0.1
6	C - N - C	0.1 – 5.0 - 0.1
7	H - N - H	0.1 – 5.0 - 0.1
8	P - N - P	0.1 – 5.0 - 0.1
9	D - N - D	0.1 – 5.0 - 0.1
10	N - C - N	5.0 – 0.2 – 5.0
11	N - H - N	5.0 – 0.1 – 5.0
12	N - P - N	5.0 – 0.1 – 5.0
13	N - D - N	5.0 – 0.1 – 5.0
14	No spray (without fungicides)	-

Design and layout

Design : Randomized Block Design

Plot size : 3.0 x 5.0 m^2

Spacing : 30 x 10 cm

Genotype : KRG-1

Season *Kharif*

Year	**2002**	**2003**
Date of sowing :	20.06.2002	18.06.2003
Date of I spray :	5.08.2002	1.08.2003
Date of II spray :	15.08.2002	11.08.2003
Date of III spray :	25.08.2002	21.08.2003

In each treatment ten plants were randomly selected and tagged. Disease intensity was recorded at 55, 70 and 85 DAS. The first spray was given immediately after the appearance of rust pustules on lower leaves of the plant *i.e.,* 46 DAS during 2002 and 44 DAS during 2003 and two subsequent sprays were given at 10 days interval.

Observations recorded

Recording of observations on per cent disease index, pod and haulm yield and further calculation of per cent increase in yield over control and benefit cost ratio was done as already explained in crop loss assessment trial.

Statistical analysis and interpretation

The data obtained from the laboratory and field experiments were statistically analyzed by following the standard procedures (Panse and Sukhatme, 1967). The percentage values were converted to angular values wherever required.

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

The present investigations were carried out both in the laboratory and field during 2002-03 and 2003-2004. Laboratory, glasshouse and all the field experiments were carried out at Regional Agricultural Research Station, Raichur, Karnataka, while some laboratory and glasshouse experiments were under taken at Department of Plant Pathology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka. The results of the investigations are presented here under.

DISEASE SURVEY AND SURVEILLANCE

Survey for the severity and distribution of the disease

A fixed plot survey was carried out to know the severity (Plate 3) and distribution of groundnut rust during *kharif* 2002 (Fig.1) and 2003 (Fig. 2) in major groundnut growing areas of Nortern Karnataka. The survey included farmers fields in areas of Raichur, Koppal, Bidar, Gulbarga, Bagalkot, Gadag, Dharwad, Bijapur, Haveri, Bellary and Belgaum districts. The survey comprised of five villages in each taluk with five farmers' fields In each village, the disease incidence was recorded at 65-85 days after sowing as per 1-9 scale and later expressed as per cent disease index. The observations are presented in Table 1 & 2.

The data indicated that, rust of groundnut caused by *P. arachidis* was prevalent in very severe form during *kharif* 2002 and 2003 (48.91%) in groundnut growing areas of Nortern Karnataka. The severity was comparatively more during 2003 (52.46%) than 2002 (45.39%) (Table 1).

Table 1: Per cent disease index of groundnut rust (*P. arachidis*) during *kharif* 2002 and 2003 in northern Karnataka

District	Per cent disease index (PDI)			
	Taluk	2002	2003	Average
Bagalkot	Bagalkot	53.57	61.59	57.59
	Hungund	49.80	61.45	55.63
Average		**51.69**	**61.52**	**56.61**
Belgaum	Gokak	**37.07**	**38.52**	**37.79**
Bellary	Bellary	40.09	40.62	40.36
	Hospet	49.15	52.53	50.84
	Siruguppa	45.01	52.31	48.66
Average		**43.97**	**47.29**	**45.63**
Bidar	Bhalki	43.03	56.5	49.77
	Bidar	37.77	46.61	42.19
Average		**40.40**	**51.56**	**45.98**
Bijapur	Bijapur	38.84	41.99	40.41
	Muddebihal	46.14	50.99	48.54
Average		**42.48**	**46.47**	**44.48**
Dharwad	Dharwad	34.62	39.17	36.89
	Hubli	36.26	39.20	37.73
Average		**35.44**	**39.19**	**37.31**
Gadag	Gadag	**40.02**	**44.57**	**42.30**
Gulbarga	Aland	52.72	69.71	61.21
	Gulbarga	49.36	55.90	52.63
	Shahapur	56.56	70.95	63.76
	Shorapur	57.23	69.66	63.45
Average		**53.97**	**66.56**	**60.26**
Haveri	Haveri	**41.64**	**43.71**	**42.68**
Koppal	Gangavati	56.20	70.49	63.35
	Koppal	55.23	68.33	61.78
	Kushtagi	55.23	68.33	61.78
	Yelburga	44.50	57.94	47.88
Average		**52.79**	**66.27**	**59.53**
Raichur	Deodurga	63.34	73.33	68.33
	Lingasgur	56.28	63.80	60.04
	Manvi	57.35	73.44	65.40
	Raichur	58.32	75.49	66.90
	Sindhnoor	63.67	70.05	66.85
Average		**59.79**	**71.22**	**65.50**
State Average		**45.39**	**52.46**	**48.91**

Table 2: Survey on the incidence of groundnut rust caused by *P. arachidis* during *kharif* 2002 and 2003 in different villages of northern Karnataka

Taluk	Places visited	Rainfed / Irrigated	Varieties grown	Per cent disease index (PDI)		
1	2	3	4	2002	2003	Average
BAGALKOT DISTRICT						
Bagalkot	Anagawadi	Rainfed	TMV-2	52.64	61.76	57.20
	Bevoor	Rainfed	TMV-2	54.66	60.66	57.66
	Kamatagi	Rainfed	TMV-2	56.88	62.66	59.77
	Muchakandi	Irigated	TMV-2	57.75	60.88	59.31
	Sunag	Irrigated	TMV-2	46.00	61.98	53.99
Average				**53.59**	**61.59**	**57.59**
Hungund	Amingad	Rainfed	TMV-2	47.98	69.32	58.65
	llakal	Rainfed	TMV-2	48.65	62.66	55.66
	Kandagallu	Rainfed	S-206	40.88	48.19	44.54
	Karadi	Rainfed	TMV-2	48.63	59.33	53.98
	Kellur	Rainfed	TMV-2	62.88	67.76	65.32
Average				**49.80**	**61.45**	**55.63**
BELLARY DISTRICT						
Bellary	Hagari	Irrigated	S-206	43.33	42.89	43.11
	Kolur	Rainfed	TMV-2	41.11	40.67	40.89
	Kurugodu	Irrigated	S-206	38.89	39.11	39.00
	Moka	Rainfed	TMV-2	39.33	40.45	39.89
	Yemmiganur	Rainfed	TMV-2	37.78	40.00	38.89
Average				**40.09**	**40.62**	**40.36**
Hospet	Daroji	Irrigated	S-206	52.89	60.22	56.56
	Kampli	Irrigated	TMV-2	39.55	42.00	40.78
	Kamalapur	Irrigated	S-206	48.89	55.33	52.11
	Kariganur	Irrigated	TMV-2	52.22	56.67	54.45
	M.M.Halli	Irrigated	TMV-2	52.22	48.44	50.33
Average				**49.15**	**52.53**	**50.84**
Siraguppa	Beerahalli	Rainfed	TMV-2	42.89	39.33	41.11
	Hacholli	Irrigated	S-206	46.60	56.68	51.64
	Karur	Irrigated	TMV-2	40.89	45.56	43.23
	Kottalachinta	Irrigated	KRG-1	54.89	75.78	65.34
	Raravi	Irrigated	TMV-2	39.78	44.22	42.00
Average				**45.01**	**52.31**	**48.66**

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BELGAUM DISTRICT						
Gokak	Ankalagi	Rainfed	TMV-2	39.11	42.00	40.56
	Arabhavi	Rainfed	R-8808	39.56	36.22	37.89
	Karikatti	Rainfed	TMV-2	35.33	37.78	36.56
	Koujalagi	Rainfed	TMV-2	36.22	38.60	37.41
	Mamadapur	Rainfed	TMV-2	35.11	38.00	36.56
Average				**37.07**	**38.52**	**37.79**
BIDAR DISTRICT						
Bhalki	Byalahalli	Irrigated	KRG_1	41.34	49.30	45.32
	Chalkapur	Rainfed	TMV-2	42.40	55.08	48.74
	Halbarga	Irrigated	TMV-2	43.33	56.74	50.04
	Mehekar	Rainfed	TMV-2	48.30	58.08	53.19
	Nittur	Irrigated	S-206	39.78	63.30	51.54
Average				**39.10**	**49.46**	**42.73**
Bidar	Janwad	Irrigated	TMV-2	33.99	54.20	44.09
	Kamathova	Irrigated	TMV-2	36.45	41.56	39.00
	Maskhal	Rainfed	TMV-2	41.08	44.10	42.59
	Nanbad	Irrigated	TMV-2	39.12	44.54	41.83
	Nagora	Rainfed	TMV-2	38.23	48.64	43.43
Average				**37.77**	**46.61**	**42.19**
BIJAPUR DISTRICT						
Bijapur	Honawad	Rainfed	S-206	37.33	38.67	38.00
	Khakandki	Irrigated	TMV-2	41.11	41.33	41.22
	Mamadapur	Rainfed	TMV-2	37.56	49.04	43.30
	Hitnalli	Irrigated	KRG-1	38.22	39.56	38.89
	Tikota	Rainfed	TMV-2	39.99	41.33	40.66
Average				**38.84**	**41.97**	**40.41**
Muddebihal	Handral	Rainfed	TMV-2	49.98	54.63	52.31
	Kodaganur	Irrigated	S-206	43.11	51.30	47.1
	Handral	Rainfed	TMV-2	47.52	43.56	45.54
	Talikoti	Irrigated	TMV-2	44.67	53.33	49.00
	Tangadagi	Irrigated	TMV-2	45.29	51.97	48.63
Average				**46.114**	**50.958**	**48.54**

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DHARWAD DISTRICT						
Dharwad	Garag	Rainfed	TMV-2	34.67	41.11	37.89
	Hosatti	Rainfed	TMV-2	35.55	38.43	36.99
	Kanvihosaour	Rainfed	TMV-2	35.56	38.65	37.11
	Mugali	Irrigated	GPBD-4	35.76	42.11	38.93
	Narendra	Irrigated	TMV-2	31.55	35.54	33.54
Average				**34.62**	**39.17**	**36.90**
Hubli	Byahatti	Rainfed	TMV-2	33.55	41.56	37.55
	Ingalahalli	Rainfed	TMV-2	36.22	41.32	38.77
	Manakod	Irrigated	TMV-2	37.34	34.89	36.12
	Sattur	Rainfed	TMV-2	38.67	41.56	40.12
	Unakal	Rainfed	TMV-2	35.54	36.65	37.00
Average				**36.26**	**39.20**	**37.73**
GADAG DISTRICT						
Gadag	Hulkoti	Irrigated	TMV-2	41.11	47.56	44.33
	Hombal	Irrigated	TMV-2	42.00	44.66	43.33
	Harlapur	Irrigated	TMV-2	42.38	47.53	44.96
	Kanaginahal	Rainfed	TMV-2	35.75	40.43	38.09
	Narasapur	Rainfed	TMV-2	38.87	42.67	40.77
Average				**40.02**	**44.57**	**42.30**
GULBARGA DISTRICT						
Aland	Gola(B)	Rainfed	TMV-2	48.06	61.74	54.90
	Kadaganchi	Irrigated	TMV-2	51.96	74.86	63.41
	Karahari	Irrigated	TMV-2	48.18	71.32	59.75
	Narona	Rainfed	TMV-2	60.20	77.08	68.64
	Naroria	Irrigated	TMV-2	55.20	63.56	59.38
Average				**52.72**	**69.71**	**61.21**
Gulbarga	Bagewadi	Rainfed	TMV-	54.22	61.32	57.77
	Halaharti	Irrigated	2GPBD-4	21.54	26.44	23.99
	Kerur	Rainfed	TMV-2	54.66	61.98	58.32
	Kadbur	Irrigated	TMV-2	47.98	61.98	54.98
	Sannur	Irrigated	TMV-2	58.40	67.76	63.08
Average				**49.36**	**55.90**	**52.63**
Shahapur	Bevinahalli	Rainfed	KRG-1	50.65	71.76	61.21
	Gogipet	Irrigated	TMV-2	60.42	69.74	65.08
	Harsgundi	Irrigated	TMV-2	60.65	74.20	67.43
	Hattigudur	Irrigated	S-206	61.32	77.74	69.53
	Madnal	Rainfed	TMV-2	49.76	61.32	55.54
Average				**56.56**	**70.95**	**63.76**

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Shorapur	Diggi	Rainfed	TMV-2	61.54	72.88	67.21
	Kembavi	Irrigated	TMV-2	59.10	75.08	67.09
	Kakkeri	Rainfed	KRG-1	47.78	62.64	52.21
	Timmapur	Irrigated	S-206	58.86	65.74	62.30
	Thintani	Rainfed	TMV-2	58.88	71.98	65.43
Average				**57.23**	**69.66**	**63.45**
			HAVERI DISTRICT			
Haveri	Devihosur	Irrigated	KRG-1	44.00	50.44	47.22
	Guttal	Irrigated	TMV-2	39.34	43.10	41.22
	Havanur	Irrigated	S-206	41.12	42.38	41.75
	Hosaritti	Irrigated	TMV-2	43.30	42.66	42.98
	Karjagi	Rainfed	TMV-2	40.45	39.98	40.21
Average				**41.64**	**43.71**	**42.67**
			KOPPAL DISTRICT			
Yelburga	Benakal	Rainfed	TMV-2			
	Kukanoor	Rainfed	Mardur	60.40	68.86	44.63
	Mangalore	Rainfed	Local	40.84	54.42	47.63
	Mudhol	Rainfed	S-230	43.85	61.45	52.65
	Ryavanki	Rainfed	Mardur	39.32	43.87	41.59
			Local	38.10	61.10	49.60
			TMV-2			
Average				**44.50**	**57.94**	**47.88**
Kushtagi	Chalageri	Rainfed	TMV-2	55.98	68.88	62.43
	Gudadur	Irrigated	S-206	58.72	73.54	66.13
	Hanumsagar	Rainfed	TMV-2	54.55	64.86	59.71
	Mudenur	Rainfed	TMV-2	46.64	63.20	54.92
	Tavaragera	Irrigated	S-206	60.28	71.18	65.73
Average				**55.23**	**68.33**	**61.78**
Koppal	Gondbal	Irribated	TMV-2			
	Halageri	Irrigated	Mardur	61.86	81.52	71.69
	Irakalgada	Irrigated	Local	39.32	58.60	48.96
	Kataraki	Rainfed	Mardur	42.14	51.76	46.95
	Kinnal	Rainfed	Local	43.97	65.76	54.87
			S-230	39.45	41.08	40.27
			Mardur			
			Local			
Gangavati	Anegundi	Irrigated	TMV-2	56.06	73.98	65.02
	Hulihidar	Rainfed	S-230	46.68	56.99	51.83
	Kanakagiri	Irrigated	S-230	53.54	70.42	61.98
	Navali	Irrigated	TMV-2	51.84	70.44	61.14
	Venkatagiri	Rainfed	TMV-2	54.90	80.64	67.77
Average				**56.20**	**70.49**	**63.35**

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RAICHUR DISTRICT						
Deodurga	Arakara	Irrigated	TMV-2	67.06	79.74	73.40
	Jadaladinni	Rainfed	TMV-2	59.72	67.50	63.61
	Jalahalli	Irrigated	KRG-1	65.96	71.96	68.96
	Kapur	Rainfed	TMV-2	62.42	75.52	68.97
	Masarakal	Irrigated	TMV-2	61.52	71.94	66.73
Average				**63.34**	**73.33**	**68.33**
Sindhnoor	Balaganur	Rainfed	TMV-2	66.86	73.98	70.42
	Javalagera	Irrigated	TMV-2	66.86	71.95	69.40
	M. gudda	Irrigated	TMV-2	62.66	73.52	68.09
	Turvihal	Rainfed	S-206	58.42	66.86	62.64
	Salagund	Irrigated	TMV-2	63.54	63.94	63.74
Average				**63.67**	**70.05**	**66.86**
Lingasgur	Guragunta	Irrigated	S-206	59.30	65.54	62.42
	Madkihal	Irrigated	TMV-2	61.92	67.76	64.84
	Maski	Rainfed	TMV-2	50.44	63.98	57.21
	Mudgal	Rainfed	TMV-2	57.10	60.42	58.76
	Santekallur	Rainfed	TMV-2	52.66	61.32	56.99
Average				**56.28**	**63.80**	**60.04**
Manvi	Hirekotnekal	Rainfed	TMV-2	42.42	60.88	51.65
	Jangamrahalli	Irridated	TMV-2	59.32	82.18	70.75
	Kurdi	Irrigated	TMV-2	61.76	72.42	67.09
	Mallat	Rainfed	TMV-2	63.08	74.20	68.64
	Neermanvi	Irrigated	KRG-1	60.18	77.54	68.86
Average				**57.35**	**73.44**	**65.40**
Raichur	Chandrabanda	Irrigated	TMV-2	66.20	77.98	72.09
	Ashapur	Irrigated	TMV-2	61.76	78.88	70.32
	Heerapur	Irrigated	R-9251	39.45	66.42	52.93
	Kudlur	Irrigated	R-8808	63.10	76.42	69.76
	Yaragera	Irrigated	R-8808	61.10	77.74	69.42
Average				**58.32**	**75.49**	**66.90**

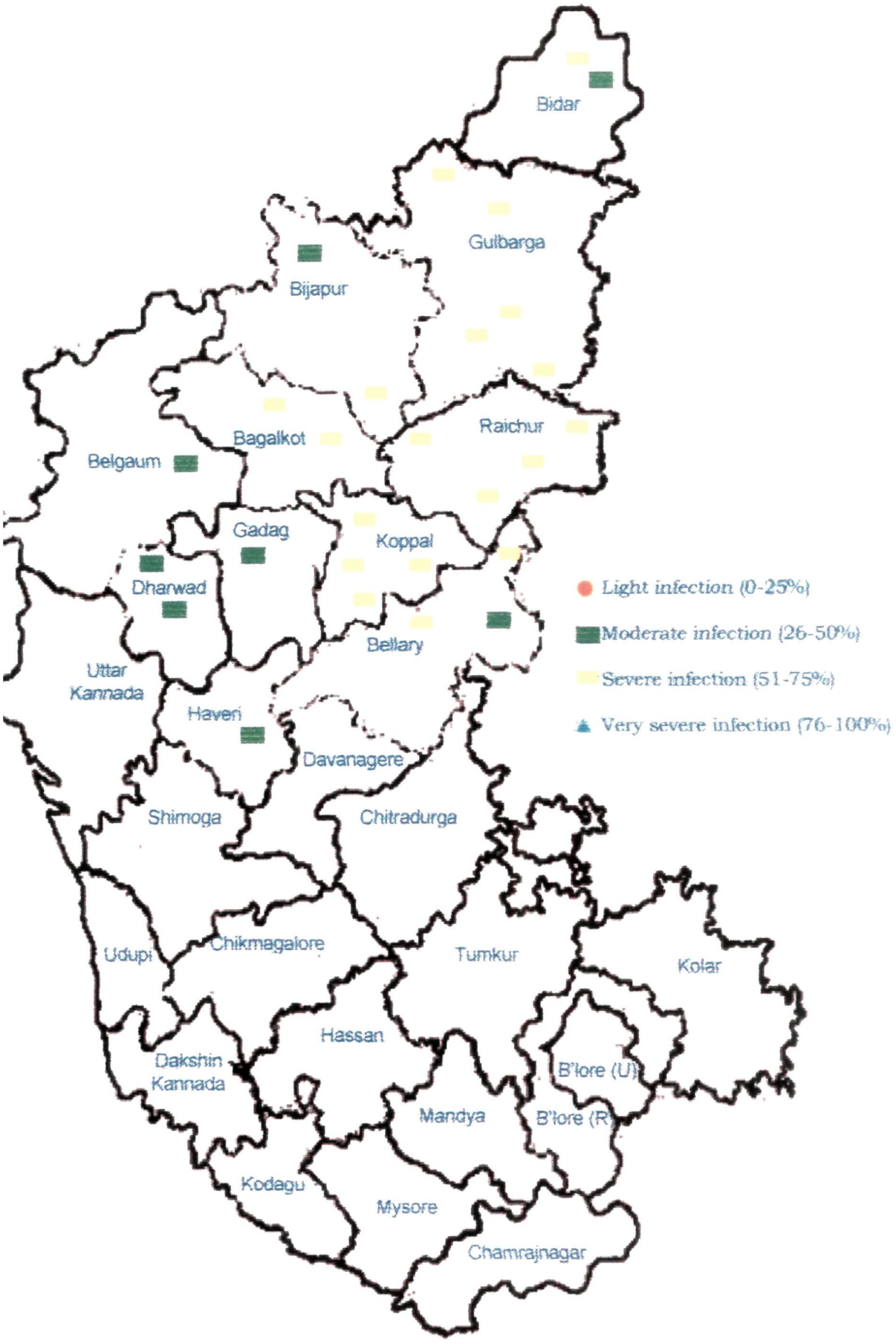


Fig. 1. Severity of groundnut rust (*P. arachidis*) in different districts of Northern Karnataka during *kharif* 2002

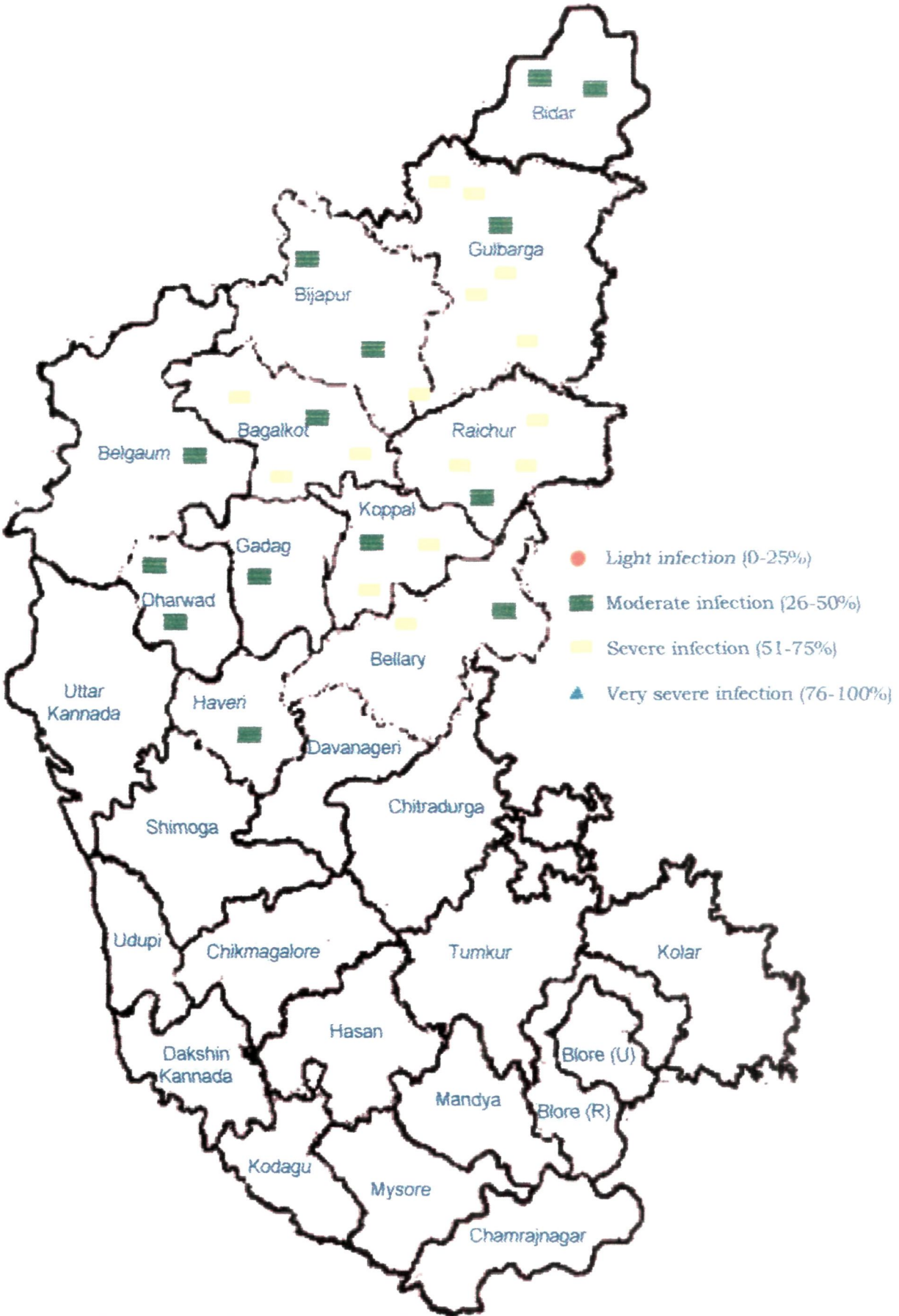


Fig. 1. Severity of groundnut rust (*P. arachidis*) in different districts of Northern Karnataka during *kharif* 2003

Plate 3. Development of rust of groundnut in the field.

1. Yellowish flecks on adaxial surface, 2. Orange coloured pustules on abaxial surface, 3. Coalescence of yellow flecks on adaxial surface, 4. Orange colored pustules on adaxial surface, 5. Pustules on petioles and 6. On branches, 7. View of severely infected field, 8. Closer view of severely infected field.

Among eleven districts surveyed, maximum disease severity was recorded in Raichur district (65.50%) followed by Gulbarga (60.26%) and Koppal (59.53%) and least was in Dharwad (37.31%) (Table 1). Arakera village in Deodurga taluk in Raichur district recorded the highest average maximum disease severity of more than 73 per cent (Table 2). The lowest average minimum disease severity of 23.99 per cent was recorded in Halaharti village of Gulbarga taluk of Gulbarga district followed by Narendra village (33.54%) of Dharwad taluk and Manakod village (36.12%) of Hubli taluk & Dharwad district.

The average disease severity varied in various locations in different districts owing to varied agroclimatic conditions, inoculum potential and different varieties cultivated. The survey in Raichur district, which included 25 villages from 5 taluks, revealed that the average severity ranged from 51.65 to 73.40 per cent. The average maximum disease severity was recorded in Arakera village (73.40%) of Deodurga taluk followed by Chandrabanda village (72.09%) of Raichur taluk and Jangamarahalli village (70.75%) of Manvi taluk. The average minimum disease severity of 51.65 per cent in Hirekotnekal village of Manvi taluk followed by Heerapur village (52.93%) of Raichur taluk and 56.99 per cent in Santekallur village of Lingasagur taluk (Table 2).

In Gulbarga district, the survey conducted in 20 villages of four taluks revealed that, average maximum disease severity ranged from 23.99 to 69.53 per cent. The maximum disease severity was observed in Hattigudur village (69.53%) of Shahapur taluk followed by Narona (68.64%) of Aland taluk and

Harsgundi village (67.43%) of Shahapur taluk. Whereas, the minimum average disease severity of 23.99 per cent was observed in Halaharti village of Gulbarga taluk followed by Gola (B) village (54.90%) of Aland taluk and Kadbur village (54.98%) of Gulbarga taluk.

Among twenty villages belonging to four taluks surveyed in Koppal district, average maximum disease severity was recorded in Gondbal (71.69%) of Koppal taluk followed by Venkatagiri (67.77%) of Gangavati taluk and Gudadur (66.13%) of Kushtagi taluk. The average disease severity in the district ranged from 40.27 to 71.69 per cent. The average minimum disease severity of 40.27 per cent was recorded in Kinnal village of Koppal taluk followed by Mudhol (41.59%) and Benakal (44.63%) village of Yelburga taluk.

The average disease severity in Dharwad district ranged from 33.54 to 40.12 per cent. The average maximum disease severity of 40.12 per cent was observed in Sattur village of Hubli Taluk followed by Mugali (38.93%) village of Dharwad taluk and Inglahalli (38.77%) village of Hubli Taluk. Narendra village of Dharwad taluk recorded least average disease severity (33.54%) followed by Manakod (36.12%) village of Hubli taluk and 36.99 per cent in Hosatti village of Dharwad taluk (Table 2).

CROP LOSS ASSESSMENT

Field experiments were carried out during *kharif* 2002 and *kharif* 2003 to estimate and compare the losses caused by the rust on groundnut varieties *viz.*, KRG -1 (Susceptible) and K-134 (Moderately resistant) using hexaconazole. Spray schedule was implemented irrespective of disease appearance from 40 days after sowing (DAS) and imposed at weekly interval

in respective treatments. The disease appeared on 46 DAS during 2002 and at 44 DAS during 2003 on both groundnut cultivars. The results are presented in Table 3, 4, 5, 6, 7 & 8 and Fig. 3 & 4.

KRG-1

Per cent disease index (PDI)

The mean PDI in differentially sprayed groundnut plots ranged from 16.30 to 24.06, while it was 47.65 in untreated control (Table 3 and Plate 4). At 47 DAS (7 days after first spray), PDI was significantly reduced when compared to the untreated control. Disease advancement also considerably minimized on groundnut crop receiving subsequent fungicide sprays (15.56%) at 47 DAS to 37.54% at 82 DAS), while disease progress was very fast (19.63% at 47 DAS to 74.44% at 82 DAS) in unsprayed crop.

Per cent index was significantly high in plots applied with only one spray (22.21 to 37.54%) of fungicide when compared to rest of the treatments at different intervals of observation. Similarly, plots sprayed twice (40 and 47 DAS) recorded significantly high PDI at 61 DAS and also later dates of observations (19.20 to 29.26%) when compared to treatments receiving other spray schedules. Per cent disease index in plots receiving the three applications did not differ from that in plots applied with four (17.04 to 20.74%), five (15.56 to 19.27%) and six (15.93 to 19.00%) sprays of fungicides. The reduction in the disease was to the extent of 63.90 to 65.79 per cent when sprayed 3 to 6 times, while it was 49.50 to 57.60 per cent with one and two sprays, respectively (Table 3).

Table 3: Crop loss assessment due to rust of groundnut caused by *P. arachidis* in variety KRG-1 during *kharif*, 2002

Sl. No.	Treatment	DAS and Per cent Disease Index*						Mean	Per cent reduction over control	Pod yield (q/ha))	Per cent pod yield increase over control	Haulm yield (q/ha)	Per cent haulm yield increase over control
		47	54	61	68	75	82						
1.	T1 - One spray	15.56	18.52	22.21	23.11	27.44	37.54	24.06	49.50	13.12	6.14	19.41	24.10
		(23.24)*	(25.47)	(28.96)	(28.67)	(31.60)	(37.76)						
2.	T2 - Two sprays	15.13	15.89	19.20	20.01	22.21	29.26	20.28	57.64	15.90	22.64	23.28	48.84
		(22.88)	(23.50)	(25.91)	(26.58)	(28.11)	(32.73)						
3.	T3 - Three sprays	15.00	15.07	16.00	16.67	17.78	22.22	17.20	63.90	17.86	44.49	27.60	76.47
		(22.79)	(22.83)	(23.66)	(24.10)	(24.92)	(28.14)						
4.	T4 - Four sprays	14.07	14.33	17.04	17.78	19.26	20.74	17.04	64.23	20.01	61.89	28.84	84.39
		(22.03)	(22.23)	(24.31)	(24.92)	(26.02)	(27.10)						
5.	T5 - Five sprays	12.96	13.33	15.56	17.41	19.26	19.27	16.30	65.79	20.50	65.85	28.90	84.78
		(21.10)	(21.41)	(23.24)	(24.65)	(26.02)	(26.04)						
6.	T6 - Six sprays	14.07	15.90	15.93	17.41	18.89	19.00	16.86	64.60	20.43	65.29	29.13	86.25
		(22.03)	(23.50)	(23.56)	(24.64)	(25.75)	(25.84)						
7.	T7 - No spray	19.63	24.07	47.41	57.41	62.96	74.44	47.65	--	12.36	--	15.64	--
		(26.29)	(27.53)	(45.17)	(49.27)	(52.64)	(60.09)						
	S.Em±	0.68	0.93	0.66	0.64	0.86	1.3 8			0.91		1.20	
	CD at 5%	2.10	2.87	1.99	1.99	2.66	4.20			2.73		3.63	

*Values in parenthesis are angular transformed values
Date of first spray 40 DAS

Table 4: Crop loss assessment due to rust of groundnut caused by *P. arachidis* in variety KRG-1 during *kharif*, 2003

Sl. No.	Treatment	DAS and Per cent Disease Index*						Mean	Per cent reduction over control	Pod yield (q/ha)	Per cent pod yield increase over control	Haulm yield (q/ha)	Per cent haulm yield increase over control
		47	54	61	68	75	82						
1.	T1 - One spray	17.60 (26.30)	22.30 (28.18)	28.55 (31.68)	33.22 (35.18)	38.80 (38.53)	42.25 (40.53)	30.79	23.78	12.31	6.30	19.81	23.42
2.	T2 - Two sprays	19.26 (26.01)	23.33 (28.89)	24.74 (29.80)	25.70 (30.46)	30.37 (33.44)	30.38 (33.45)	25.63	53.03	15.10	30.39	22.80	42.05
3.	T3 - Three sprays	18.52 (25.47)	19.00 (25.84)	19.52 (26.25)	20.00 (26.56)	22.00 (27.97)	23.33 (28.87)	20.40	63.23	17.12	47.84	25.73	60.31
4.	T4 - Four sprays	18.00 (25.10)	19.10 (25.91)	19.15 (25.91)	19.60 (26.28)	19.63 (26.28)	21.48 (27.62)	19.49	64.02	19.12	65.11	27.71	72.64
5.	T5 - Five sprays	18.26 (25.30)	19.11 (25.92)	19.41 (26.13)	19.42 (26.14)	19.56 (26.24)	19.63 (26.30)	19.23	64.81	19.50	68.39	28.08	74.95
6.	T6 - Six sprays	18.00 (25.10)	18.02 (25.11)	18.26 (25.28)	18.30 (25.33)	18.35 (25.35)	18.52 (25.42)	18.24	66.17	19.61	69.34	28.61	78.25
7.	T7 - No spray	28.52 (32.27)	41.48 (40.52)	52.22 (46.27)	57.78 (49.47)	65.57 (54.07)	81.85 (65.91)	54.57	--	11.58	--	16.05	--
	S.Em±	0.65	0.88	0.58	0.60	1.19	1.25			0.85		1.01	
	CD at 5%	2.00	2.75	1.75	1.85	3.69	3.83			2.55		3.04	

*Values in parenthesis are angular transformed values
Date of first spray 40 DAS

Table 5: Crop loss assessment due to rust of groundnut caused by *P. arachidis* in variety K-134 during *kharif*, 2002

Sl. No	Treatment	DAS and Per cent Disease Index*						Mean	Per cent reduction over control	Pod yield (q/ha)	Per cent pod yield increase over control	Haulm yield (q/ha)	Per cent haulm yield increase over control
		47	54	61	68	75	82						
1.	T1 - One spray	15.26 (23.18)	19.90 (25.84)	22.00 (27.97)	22.74 (28.52)	23.48 (28.93)	26.96 (31.29)	21.72	30.56	14.22	7.89	21.25	13.69
2.	T2 - Two sprays	14.30 (23.80)	16.56 (23.97)	16.78 (24.20)	17.04 (24.37)	19.04 (25.85)	21.11 (27.36)	17.47	44.10	17.26	30.95	23.82	27.44
3.	T3 - Three sprays	15.93 (23.47)	16.67 (24.06)	17.10 (24.35)	17.15 (24.45)	17.65 (24.86)	20.74 (27.08)	17.54	43.92	17.53	33.00	26.66	42.10
4.	T4 - Four sprays	14.52 (22.38)	15.26 (22.95)	16.60 (24.94)	16.50 (23.97)	17.74 (24.92)	21.48 (27.62)	17.02	45.58	19.27	46.21	26.80	43.39
5.	T5 - Five sprays	14.67 (22.46)	15.15 (22.90)	15.52 (23.49)	16.89 (24.27)	18.00 (25.10)	20.37 (26.82)	16.77	46.38	19.57	48.48	27.06	44.78
6.	T6 - Six sprays	14.47 (22.30)	15.56 (23.23)	15.93 (23.51)	15.93 (23.51)	16.67 (24.09)	19.04 (25.86)	16.27	47.98	19.62	48.86	27.15	45.26
7.	T7 - No spray	19.26 (26.02)	23.33 (28.89)	34.44 (35.44)	30.30 (37.04)	38.52 (38.36)	41.85 (40.31)	31.28	--	13.18	--	18.69	--
	S.Em±	0.83	0.60	1.28	1.42	0.64	0.50			0.77		0.56	
	CD at 5%	2.57	1.87	3.85	4.37	1.97	1.52			2.23		1.72	

*Values in parenthesis are angular transformed values
Date of first spray 40 DAS

Table 6: Crop loss assessment due to rust of groundnut caused by *P. arachidis* in variety K-134 during *kharif*, 2003

Sl. No	Treatment	DAS and Per cent Disease Index						Mean	Per cent reduction over control	Pod yield (q/ha)	Per cent pod yield increase over control	Haulm yield (q/ha)	Per cent haulm yield increase over control
		47	54	61	68	75	82						
1.	T1 - One spray	16.63 (24.94)	20.74 (27.10)	21.48 (27.62)	21.11 (27.36)	21.85 (27.87)	23.33 (28.89)	20.86	37.18	13.00	4.92	21.33	19.62
2.	T2 - Two sprays	17.41 (24.66)	18.63 (25.58)	18.89 (25.74)	18.90 (25.77)	18.95 (25.82	20.00 (26.57)	18.80	43.39	16.69	34.70	23.84	33.70
3.	T3 - Three sprays	16.67 (24.96	16.67 (24.06)	18.57 (25.47)	19.26 (26.02)	20.00 (26.57)	20.74 (27.08)	18.65	43.84	17.48	41.08	25.92	45.37
4.	T4 - Four sprays	16.26 (24.52)	18.52 (25.47)	19.63 (26.29)	20.00 (26.56)	21.48 (27.61)	22.22 (28.13)	19.69	40.71	18.31	47.78	26.01	45.87
5.	T5 - Five sprays	16.67 (24.08)	18.15 (25.20)	19.26 (26.02)	19.26 (26.01)	20.00 (26.57)	20.74 (27.10)	19.01	42.76	18.42	48.67	26.50	48.62
6.	T6 - Six sprays	15.19 (22.92)	15.93 (23.53)	16.67 (24.09)	17.78 (24.92)	18.52 (25.47)	18.55 (25.53)	17.10	48.50	19.15	54.56	26.66	49.52
7.	T7 - No spray	20.00 (26.56)	22.96 (28.64)	35.19 (36.38)	38.52 (38.34)	39.26 (38.80)	43.33 (41.17)	33.21	--	12.39	--	17.83	--
	S.Em±	0.61	0.57	0.52	0.53	0.51	0.52			0.88		0.49	
	CD at 5%	1.87	1.77	1.57	1.63	1.57	1.62			2.68		1.51	

*Values in parenthesis are angular transformed values
Date of first spray 40 DAS

Table 7: Benefit cost ratio in loss estimation trial due to rust of groundnut caused by *P. arachidis*

Spray No.	Cost of fungicides (Rs)	Labour (Rs)	Total cost (Rs)	Additional increase in pod and haulm yield over control (q/ha)				Additional Benefit Pod @ Rs. 1500/q haulm @ Rs. 50/q				Benefit cost ratio			
				KRG-1		K-134		KRG-1		K-134		KRG-1		K-134	
				2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
1.	360	80	360	P-0.76 H-3.77	0.73 3.76	0.50 2.56	1.04 3.50	P-1140* H-189 T-1329	1095 188 1283	750 128 878	1560 175 1735	3.69	3.56	2.43	4.81
2.	360+390	160	910	P-3.54 H-7.64	3.52 6.75	4.08 5.13	4.30 6.01	P-5310 H-382 T-5692	5280 338 5617	6120 256 6376	6450 300 6750	6.26	6.17	7.00	7.41
3.	360+390+420	240	1410	P-5.50 H-11.96	5.54 9.68	4.35 7.97	5.09 8.09	P-8250 H-598 T-8848	8310 484 8794	6525 399 6924	7635 404 8049	6.28	6.24	4.91	5.70
4.	360+390+420+450	320	1940	P-7.65 H-13.20	7.54 11.60	6.09 8.11	5.92 8.16	P-11475 H-660 T-12135	11310 580 11890	9135 405 9540	8880 408 9288	6.25	6.13	4.91	4.79
5.	360+390+420+450+480	400	2500	P-8.14 H-13.26	7.92 12.03	6.39 8.37	6.03 8.67	P-12210 H-663 T-12873	11880 601 12481	9585 418 10003	9045 433 9478	5.14	4.99	4.00	3.79
6.	360+390+420+450+480+510	480	3090	P-8.07 H-13.49	8.03 12.56	6.44 8.46	6.76 8.83	P-12105 H-674 T-12779	12045 628 12673	9660 423 10083	10140 441 10581	4.13	4.10	3.26	3.42

P - Pod **H** - Haulm **T** - Total

Note : Cost of chemical (Hexaconazole) : Rs. 600 per lit
Cost of labour/spray/ha : Rs. 90/- (Male-Rs. 50/-+Female-Rs. 40/-)
I spray : 600 lit IV spray : 750 lit
II spray : 650 lit V spray : 800 lit
III spray : 700 lit VI spray : 850 lit

Table: 8 Effect of number of sprays of hexaconazole on mean PDI of rust, pod and haulm yield (q/ha), loss in pod and haulm yield (q/ha) and mean benefit cost ratio (BCR) in KRG-1 and K-134 varieties of groundnut during 2002-03.

Sl. No.	Treatment	KRG-1						K-134					
		Mean PDI	Mean Pod yield (q/ha)	Loss in pod yield over T6	Mean haulm yield (q/ha)	Loss in haulm yield over T6	Mean BCR	Mean PDI	Mean pod yield (q/ha)	Loss in pod yield over T6	Mean haulm yield (q/ha)	Loss in haulm yield over T6	Mean BCR
1.	T1 - One spray	27.26	12.72	36.46	19.61	34.42	3.63	21.29	14.46	25.38	21.29	20.85	3.62
2.	T2 - Two sprays	22.96	15.57	22.22	24.38	18.48	6.21	18.14	18.97	2.12	23.83	11.41	7.20
3.	T3 - Three sprays	18.76	17.49	12.63	26.67	10.83	6.26	18.10	17.51	9.64	26.29	2.26	5.31
4.	T4 - Four sprays	18.35	19.57	2.24	29.40	1.71	6.19	18.35	18.79	3.04	26.40	1.85	4.85
5.	T5 - Five sprays	17.65	20.01	0.05	29.74	0.57	5.07	17.89	19.00	1.96	26.78	0.44	3.90
6.	T6 - Six sprays	17.55	20.02	0	29.91	0	4.12	16.66	19.38	0	26.90	0	3.34
7.	T7 - No spray	51.12	11.97	40.20	15.84	47.04	--	32.25	12.79	34.00	18.26	32.11	--

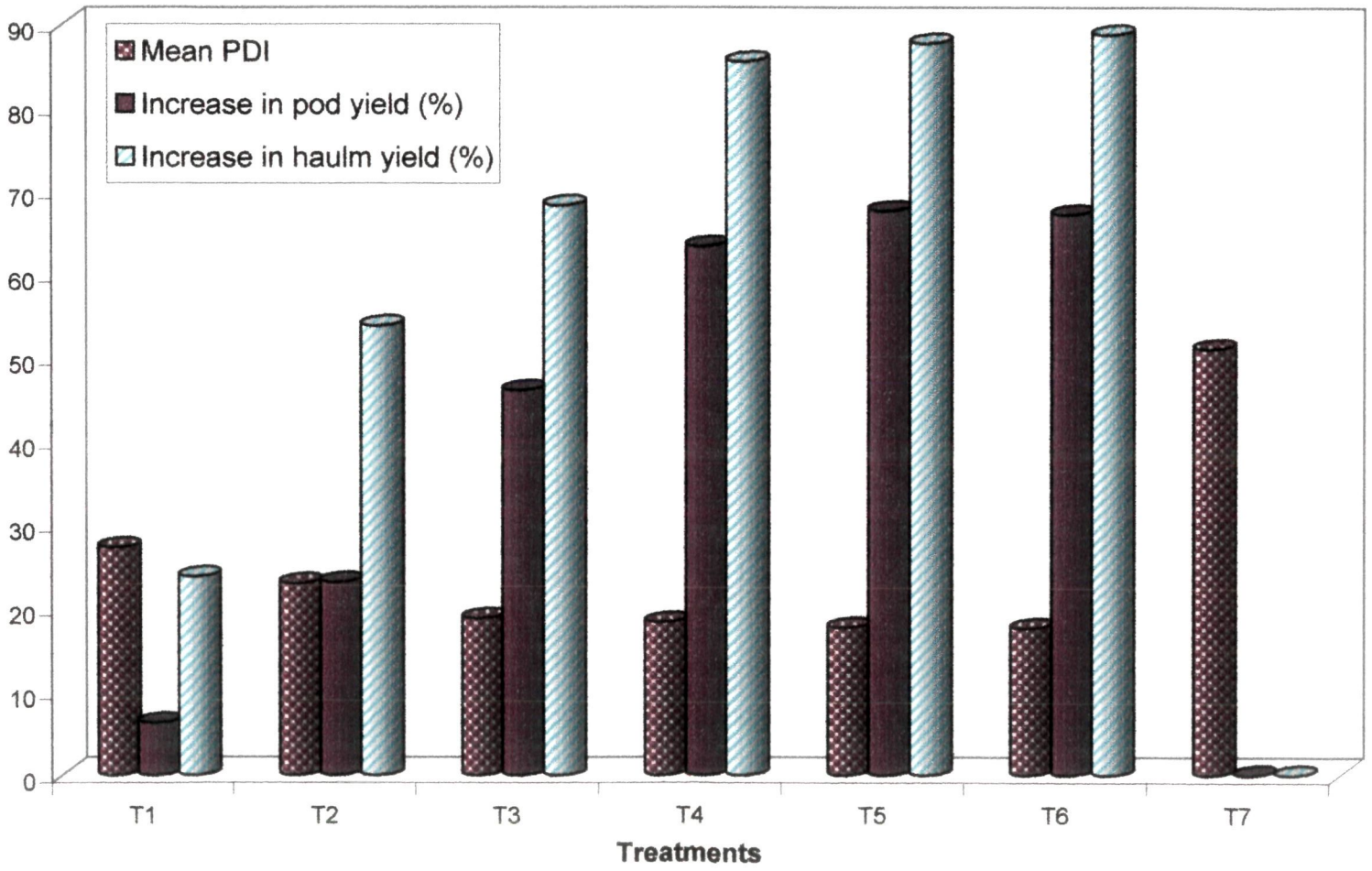


Fig. 3. Effect of number of hexaconazole (0.1%) sprays on mean PDI, increase in pod and haulm yield of groundnut (KRG-1).

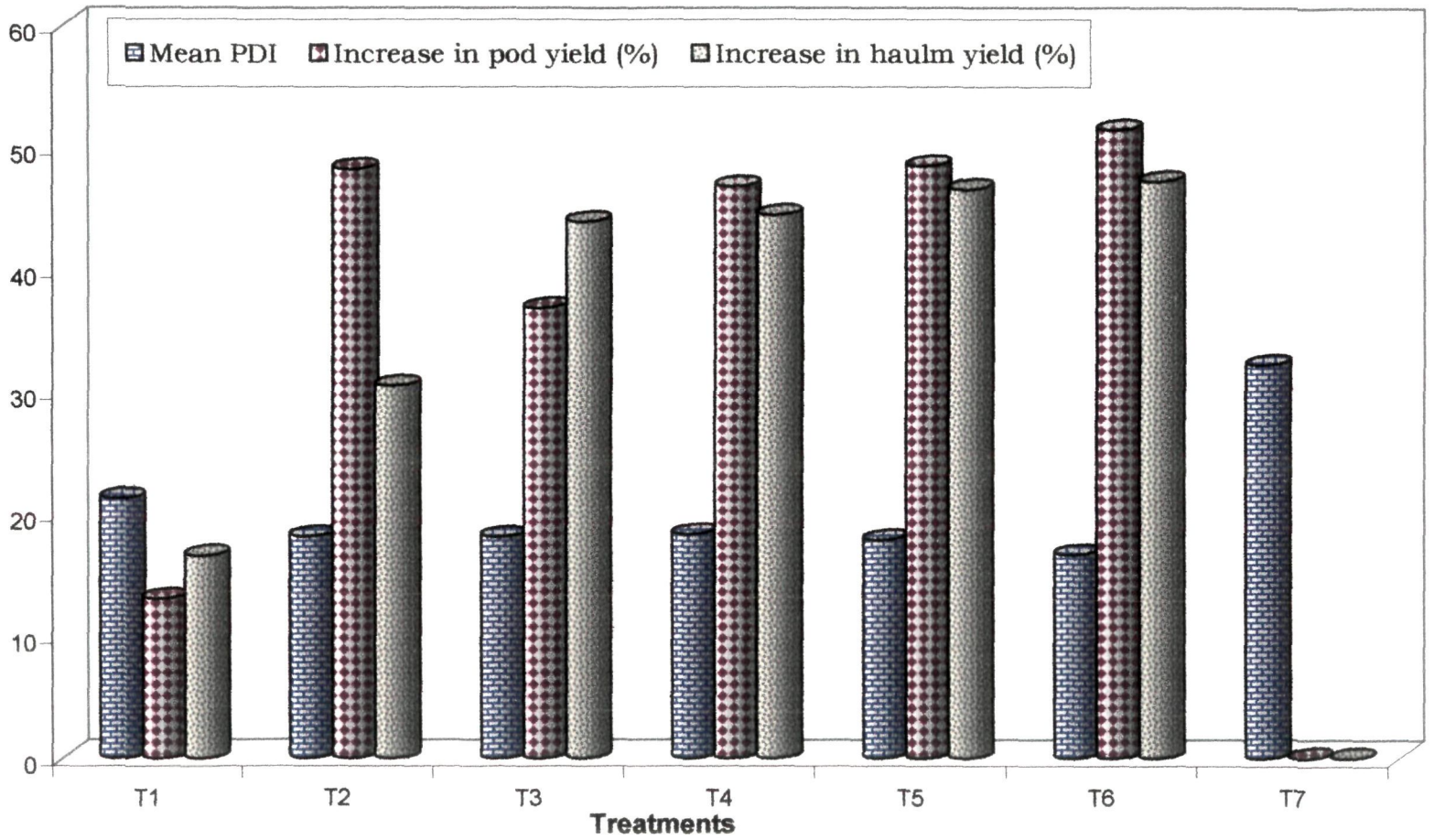


Fig. 4. Effect of number of hexaconazole (0.1%) sprays on mean PDI, increase in pod and haulm yield of groundnut (K-134).

Experimental field view

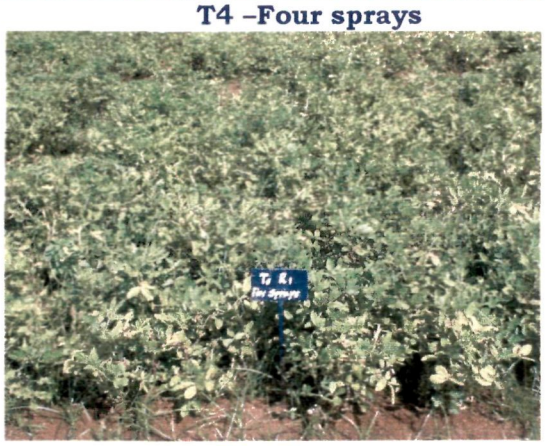
T1 –One spray

T2 –Two sprays

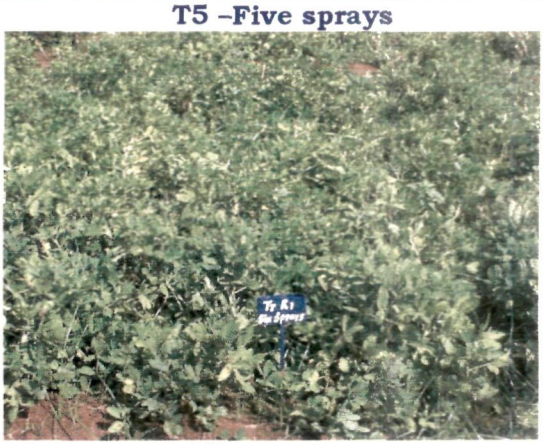
T3 –Three sprays

T4 –Four sprays

T5 –Five sprays



T6 –Six sprays



T7 –No spray

Plate 4. Effect of different sprays of hexaconazole (0.1%) on severity of rust on susceptible groundnut variety, KRG-1.

The mean per cent disease index ranged from 18.24 to 54.57 per cent in different treatments during the successive year 2003 (Table 4). The PDI was significantly less (17.60%) by one spray of fungicide at 47 DAS compared to control (28.52%). The disease progress was very fast in control treatment (28.52 to 81.85%) compared to fungicide sprayed plots (17.60 at 47 DAS and 42.25 at 82 DAS in plots sprayed once).

The plots receiving one spray of fungicide recorded significantly higher PDI (17.60 to 42.25%) when compared to rest of the treatments at different intervals of observation. Similarly, plots sprayed twice (40 and 47 DAS) recorded significantly high PDI at 68 DAS and later dates of observation (25.70 to 30.38%), while other treatments recorded significantly lesser disease severity. Further, the PDI in plots receiving three applications was found on par with 4 to 6 sprays of fungicides. Disease was reduced to an extent of 63.23 to 66.17 per cent when sprayed three to six times, while it was 23.78 per cent and 53.03 per cent with one and two sprays, respectively.

Pod yield

The dry pod yield of groundnut differed significantly among the treatments with different spray schedules (Table 3). During 2002, it was significantly reduced in untreated control (12.36 q/ha) and in crop sprayed once (13.12 q/ha) when compared to rest of the treatments. But other spray schedules, with three to six sprays pod yield did not differ (17.86 to 20.50 q/ha). The reduction in the disease due to fungicide resulted in increased pod yields. It was observed that, maximum per cent increase in pod yield was recorded in plots receiving five sprays (65.85%) and six (65.29%) and four (61.89%), while, it was 44.49 per cent in three sprays.

During the year 2003, pod yield of groundnut in plots sprayed 2 to 6 times did not vary among themselves (15.10 to 19.61 q/ha), but it was significantly more than from plots receiving only one spray (12.31 q/ha) of the fungicide and untreated control (11.58 q/ha). The highest increase in pod yield of 69.34% was recorded in six sprays followed by five (68.39%), four (65.11%), three (63.12%) and two (30.39%) sprays (Table 4).

Haulm yield

The effect of different treatments also resulted in the increased haulm yields of groundnut during both the years. The haulm yield obtained in all sprayed plots significantly differed from that of control treatment. The extent of increase in haulm yield ranged from 24.10 to 86.25 per cent in plots receiving one to six sprays during *kharif* 2002, while, it was 23.42 to 78.25 per cent during *kharif* 2003 (Table 4).

Benefit cost ratio (BCR)

Maximum BCR of 6.28 and 6.24 were obtained in the groundnut plots where three sprays of fungicide were imposed during *kharif*, 2002 and 2003, respectively (Table 7). However, average data showed the maximum benefits in spray schedules with two and three sprays of fungicide (6.21 and 6.26, respectively) received plots (Table 8). The details of the benefit cost ratio is enumerated in Table 7.

Loss in pod and haulm yield

In highly susceptible variety KRG-1, when the complete control of the disease was considered during both *kharif* 2002 and 2003, the loss of pod yield due to rust was maximum of 40.20 per cent in control plot, whereas it was 36.46, 22.22 and 12.63 per cent in plots which received one, two and

three sprays, respectively (Table 8 and Fig. 5). The highest loss of haulm yield was also recorded in control plot (47.04%) followed by plots which received one (34.42%), two (18.48%) and three (10.83%) sprays of hexaconazole. However, the mean BCR was highest in three sprays (6.25) followed by two (5.94) and five (5.17) sprays plots of loss estimation trial (Table 8).

K-134

Per cent disease index (PDI)

The mean disease index irrespective of number of sprays ranged between 16.27 to 21.72 per cent in fungicide applied crop *vis-a-vis* 31.28 in untreated control (Table 5 and Plate 5) during *kharif*, 2002. At 47 DAS, the highest PDI of 19.26 per cent was recorded from untreated control which was significantly more than rest of the treatments. However, the disease spread was comparatively more in the treatment receiving one spray of fungicide in comparison to the plots receiving 2 to 6 sprays. Groundnut crop applied with two sprays recorded the disease index of 14.30 to 21.11 per cent at different intervals of observation. The reduction of 44.10 to 43.92 per cent in disease was observed in two sprays and three sprays, respectively where as, it was least (30.56%) in plots sprayed once.

The disease severity was comparatively more during 2003 (43.33% at 82 DAS) to previous year (41.85%) in untreated control at 82 DAS (Table 6). All the six treatments recorded significantly lesser PDI compared to control at 47 DAS. The mean disease index ranged from 17.10 to 33.21 per cent in different treatments and reduction was maximum in plots receiving six sprays (48.50%) when compared to other spray schedules. Groundnut crop applied

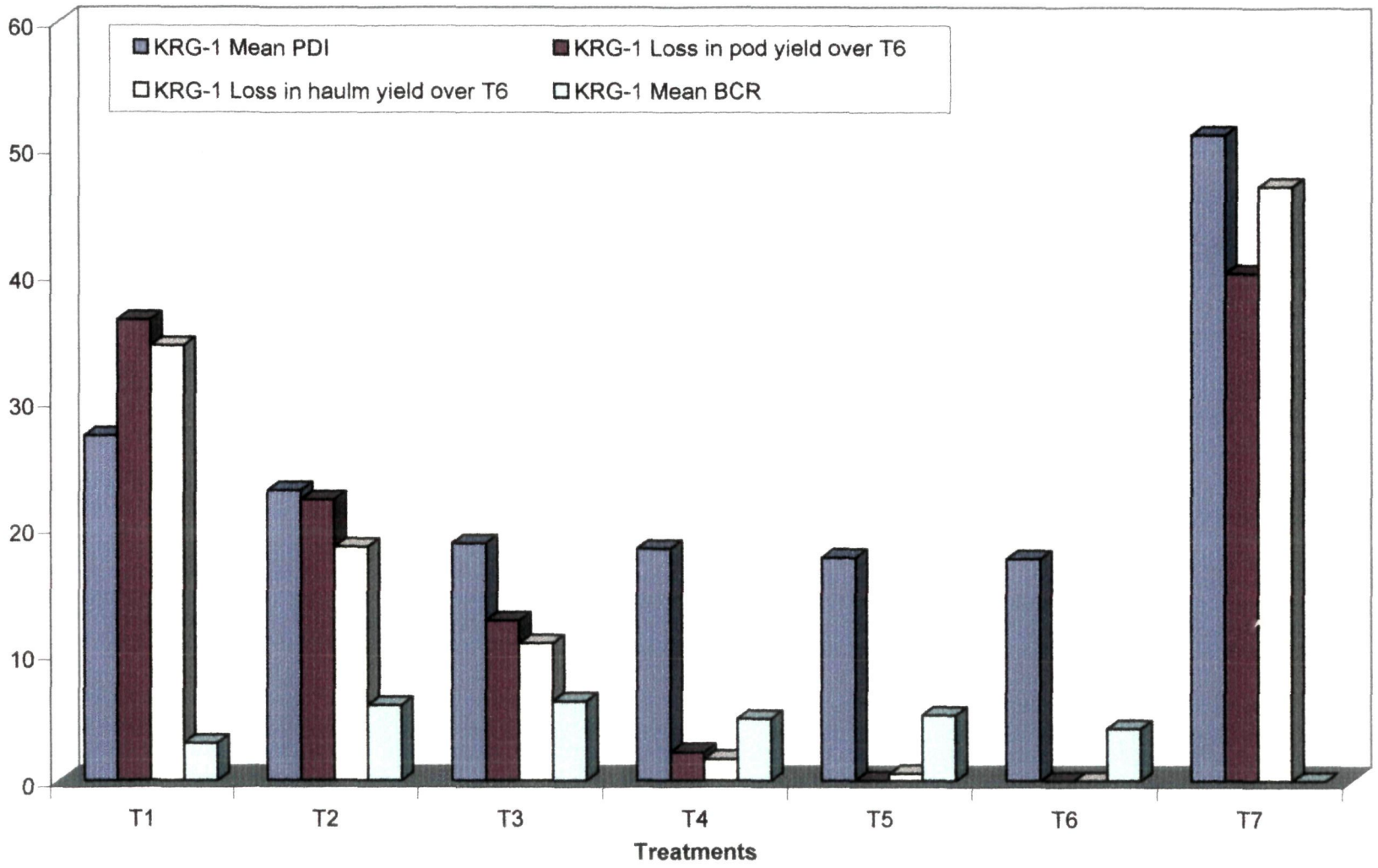


Fig. 5. Effect of number of sprays of hexaconazole on mean PDI, loss in pod and haulm yield ((kg/ha) and mean benefit cost ratio (BCR) in KRG-1 variety of groundnut during 2002-03.

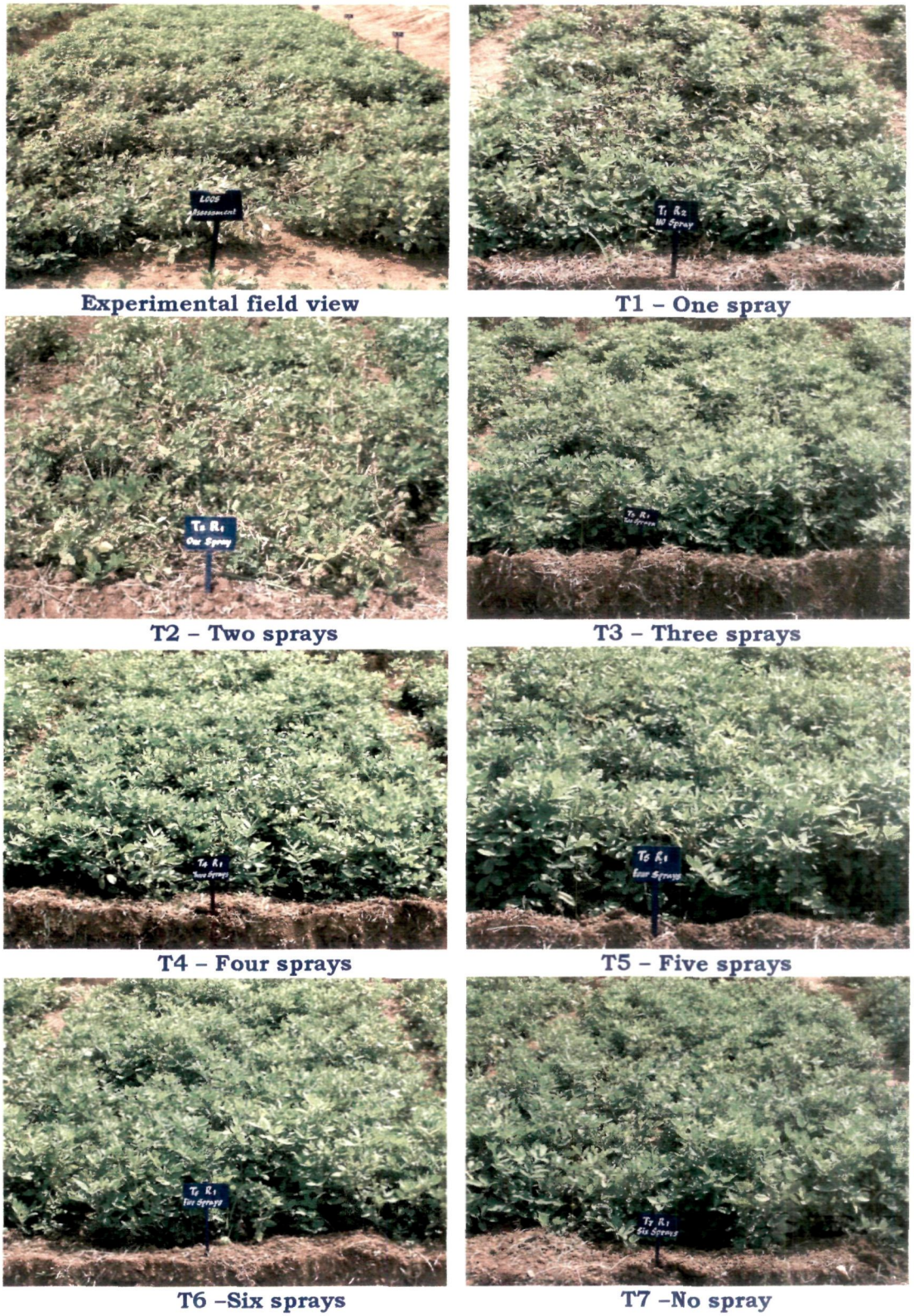


Plate 5. Effect of different sprays of hexaconazole (0.1%) on severity of rust on moderately resistant groundnut variety, K-134.

Plate 5. Effect of different sprays of Hexaconazole (0.1%) on severity of rust on susceptible groundnut variety K-134.

with two sprays recorded the disease index of 17.41 to 20.00 per cent at different intervals of observation. The reduction of 43.39 to 43.84 per cent in disease was observed in two and three sprays, respectively compared to least reduction of 37.18 per cent in plots receiving one spray.

Pod yield

Pod yield of groundnut differed significantly between the treatments with different spray schedules during 2002 (Table 5). Maximum yield was recorded in the plots receiving six sprays (19.62 q/ha) followed by five (19.57 q/ha) and four (19.27 q/ha), which were on par with the yields obtained in three sprays (17.53 q/ha) and two sprays (17.26 q/ha).

During 2003, highest pod yield of 19.15 q/ha was obtained from the plots received six sprays which is considerably superior to one spray (13.00 q/ha) and control plot (12.39 q/ha) and on par with two (16.69 q/ha), three (17.48 q/ha), four (18.31 q/ha) and five (18.42 q/ha) spray received plots (Table 6). The per cent increase over control in pod yield of 41.08 per cent was recorded in plots receiving three sprays, while it was 34.70 per cent in two sprays and least of 4.92 per cent in one spray (Table 7).

Haulm yield

During 2002, maximum haulm yield was recorded in plots receiving six sprays (27.15 q/ha), five (27.60 q/ha) and four sprays (26.80 q/ha) and on par with three sprays (26.66 q/ha). The increase in haulm yield ranged from 13.69 to 45.26 per cent in one to six sprays, respectively (Table 5). Similar

trend in haulm yield and per cent increase over control was recorded during 2003 also (Table 6).

Benefit cost ratio (BCR)

Maximum BCR of 8.19 and 7.41 was obtained from plots which received two sprays of fungicides during 2002 and 2003, respectively (Table 7). The mean results of both the years revealed similar benefit from the plot receiving two sprays (7.80) followed by three sprays (5.31) and four sprays (4.85) (Table 8).

Loss in pod and haulm yield

In moderately resistant variety K-134, when the complete control of the disease was considered during both *kharif* 2002 and 2003, the loss in pod yield due to rust was maximum (34.00%) in control plot, whereas it was 25.38 and 2.12 per cent in plots which received one and two sprays, respectively (Table 8 and Fig. 6). The highest loss in haulm yield was also recorded in control plot (32.11%) followed by plots which received one (20.85%), two (11.41%) and three (2.26%) sprays of hexaconazole (Table 8). However, the mean BCR was highest in two sprays (7.80) followed by three (5.31) and four (4.85) sprays.

Crop loss model

The study on crop loss due to rust of groundnut was carried out and an attempt was made to identify the relation between pod and haulm yield and level of incidence of disease in the form of PDI taking observation on disease at weekly interval from 47 DAS to 82 DAS for two varieties *viz.*, KRG-

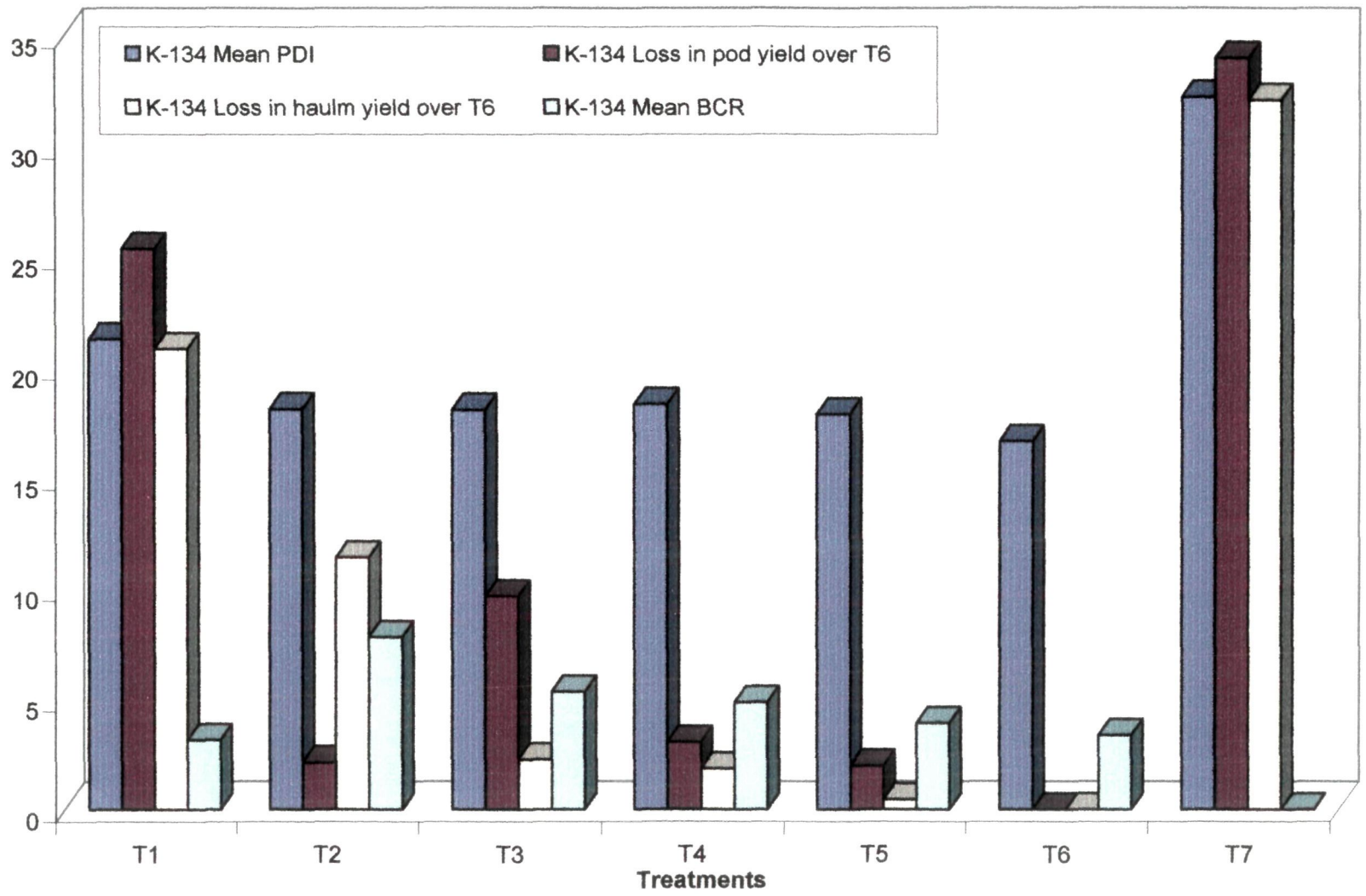


Fig. 6. Effect of number of sprays of hexaconazole on mean PDI, loss in pod and haulm yield ((kg/ha) and mean benefit cost ratio (BCR) in K-134 variety of groundnut during 2002-03.

1 and K-134 and simple linear regression models were developed and presented in Table 9.

For KRG-1 during 2002, maximum correlation coefficient of 0.85 was obtained between the PDI and the pod yield recorded at 54 DAS. During 2003, the correlation coefficient of disease with the pod yield was found to be 0.76 which was also obtained from the observations recorded at 54 DAS.

In case of the variety K-134 during 2002, it was found that maximum correlation coefficient of 0.96 was between the yield and PDI recorded on 54 DAS. Similarly for the year 2003, the maximum correlation coefficient 0.79 between yield and PDI being recorded on 61 DAS. The observed and predicted crop loss values where they have shown highest correlation coefficient were presented in Table 10 and 11(Fig. 7 and 8).

EPIDEMIOLOGICAL STUDIES

Perpetuation of uredospores of *P. arachidis* under different storage conditions.

Viability of uredospores of *P. arachidis* in different storage conditions was studied at storage periods from 5 to 50 days at an interval of five days and the results obtained are shown in Table 12.

The data revealed that, per cent viability of uredospores was decreased with increase in storage period in all the conditions tested. In room (20-25°C) and tree shade (15-20°C) conditions, viability of uredospores was observed up to 40 days of storage. At glass house (25-28°C) and field (28-30°C), viability of uredospores remained upto 20 days. While there was no germination of uredospores after 45 days of storage. The lowest per cent viable spores of

Table 9: Crop loss models showing the relation between rust PDI and yield (q/ha) of groundnut

Variety	2002	r	R^2	2003	r	R^2
	Model for pod yield			**Model for pod yield**		
KRG-1	Y= 30.688 – 0.808 PDI	0.85	0.72	Y = 23.547- 0.310 PDI	0.76	0.56
K-134	Y = 31.642- 0.823 PDI	0.96	0.92	Y = 23.789 – 0.341 PDI	0.79	0.62

Table 10: Observed and predicted pod yield (q/ha) loss values in KRG-1 during *kharif* 2002 and 2003.

Sl. No	Treatment	K-2002 (54 DAS)		K-2003 (54 DAS)	
		Observed	Predicted	Observed	Predicted
1	T1 - One spray	18.52	15.72	22.3	16.63
2	T2 - Two sprays	15.89	17.84	23.33	16.31
3	T3 - Three sprays	15.07	18.51	19.00	17.63
4	T4 - Four sprays	14.33	19.10	19.10	17.63
5	T5 - Five sprays	13.33	19.91	19.11	17.62
6	T6 - Six sprays	15.90	17.84	18.02	17.96
7	T7 - No spray	24.07	11.23	41.48	10.58

Table 11: Observed and predicted pod (q/ha) loss values in K-134 during *kharif* 2002 and 2003.

Sl. No	Treatment	K-2002 (54 DAS)		K-2003 (61 DAS)	
		Observed	Predicted	Observed	Predicted
1	T1 - One spray	19.9	15.26	21.48	16.46
2	T2 - Two sprays	16.58	17.99	18.89	17.35
3	T3 - Three sprays	16.67	17.92	18.57	17.46
4	T4 - Four sprays	15.26	19.08	19.63	18.00
5	T5 - Five sprays	15.15	17.31	19.26	17.22
6	T6 - Six sprays	15.56	16.91	16.67	18.10
7	T7 - No spray	23.33	12.44	35.19	11.79

Table 12: Effect of different storage conditions on viability of uredospores of *P. arachnids*.

Sl. No.	Storage Period (days)	Percent viable spores at different storage conditions					
		Deep freeze (-5° C)	Freeze (4-5° C)	Tree shade (15-20° C)	Room (20-25° C)	Glass house (25-28° C)	Field (28-30° C)
1	5	28.67	54.67	81.20	83.27	63.33	62.93
2	10	10.27	14.40	76.27	80.93	44.07	35.67
3	15	5.60	2.07	46.47	65.53	15.67	12.20
4	20	0	0	32.87	59.67	5.85	6.07
5	25	0	0	22.00	30.07	0	0
6	30	0	0	14.13	15.80	0	0
7	35	0	0	5.00	7.93	0	0
8	40	0	0	4.00	4.13	0	0
9	45	0	0	0	0	0	0
10	50	0	0	0	0	0	0

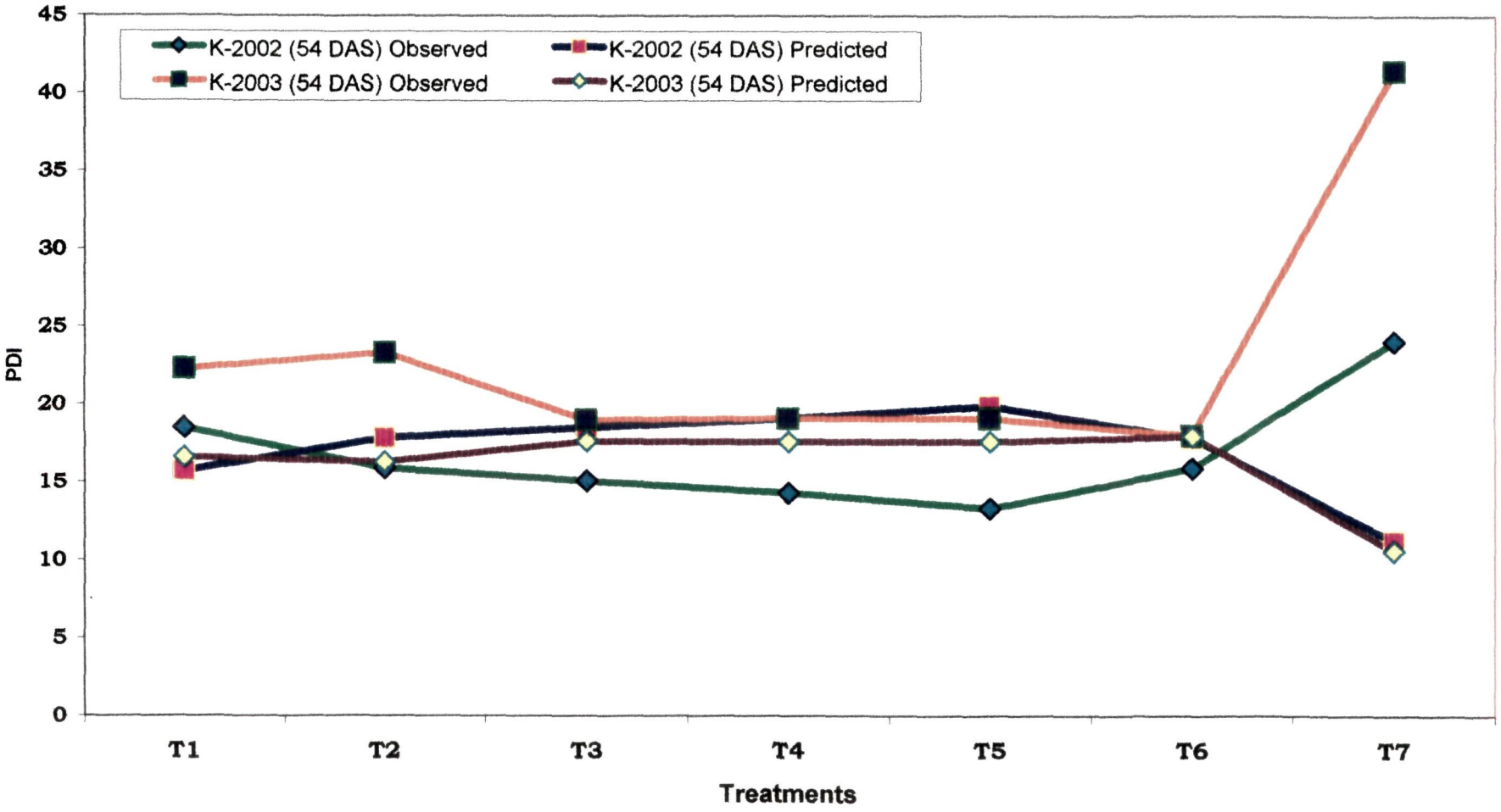


Fig. 7. Observed and predicted pod yield (q/ha) loss values in KRG-1 during *kharif* 2002 and 2003.

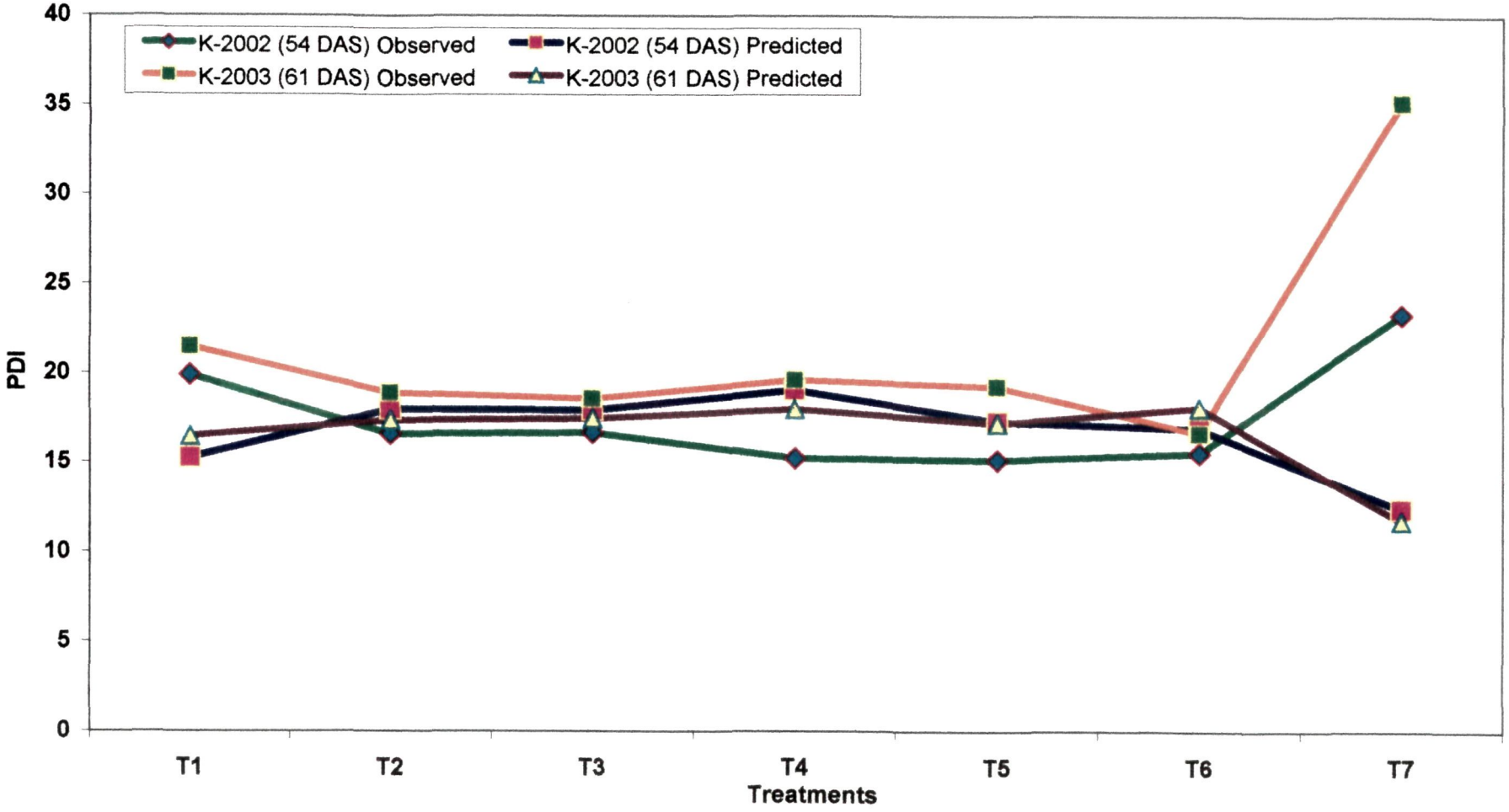


Fig. 8. Observed and predicted pod (q/ha) loss values in K-134 during *kharif* 2002 and 2003.

5.60% and 2.07% were observed in deep freeze (-5°C) and freeze (4-5°C) conditions, respectively when stored for 15 days.

Self sown groundnut plants

Survey was conducted during 2002 and 2003 (post-harvest period of groundnut crop) to search for self sown/voluntary grown groundnut plants in groundnut cultivating areas to find out the possibility of survival of uredospores of *P. arachidis* during off season (Fig. 9 & Plate 6a and 6b).

The survey conducted during off season for the possible appearance of the rust pustules on the self sown groundnut plants revealed that both self sown and voluntary grown groundnut plants found during the month of May and June showed infection of rust. However, rust infection was not observed on any of the crop and weed hosts observed in the fields of RARS, Raichur and at different places surveyed.

Search for telial stage of *P. arachidis*

An effort was made to search for the telial stage of *P. arachidis* during 2002-2003. It was observed through studies that, the teliospores were not produced/present either on fresh or stored rust affected samples from leaves, stems and petioles after the harvest and also on infected plant parts from fresh and dried fodder.

Germination of uredospores of *P. arachidis* at different temperatures

The germination of uredospores of *P. arachidis* (Plate 7) was studied at different temperature levels ranging from 5 to 40° C as mentioned in "Material and Methods". Per cent germination was recorded at every four hour interval upto 24 hours and results are presented in Table 13.

Table 13. Germination of uredospores of *P. arachidis* at different temperature levels of incubation.

Sl. No.	Temperature (° C)	Per cent germination after incubation					
		4 h	8 h	12 h	16 h	20 h	24 h
1	5	0.00	0.00	2.06	2.18	2.19	2.89
2	10	0.25	0.00	4.13	4.38	3.13	4.44
3	15	6.06	17.06	31.06	30.63	19.44	20.80
4	20	10.63	26.31	71.88	39.13	43.50	30.56
5	25	31.50	71.69	90.81	75.50	78.38	78.88
6	30	24.63	28.63	25.19	18.31	27.69	16.44
7	35	2.38	3.38	11.00	5.25	1.32	1.25
8	40	0.00	0.00	1.33	0.00	0.00	0.00

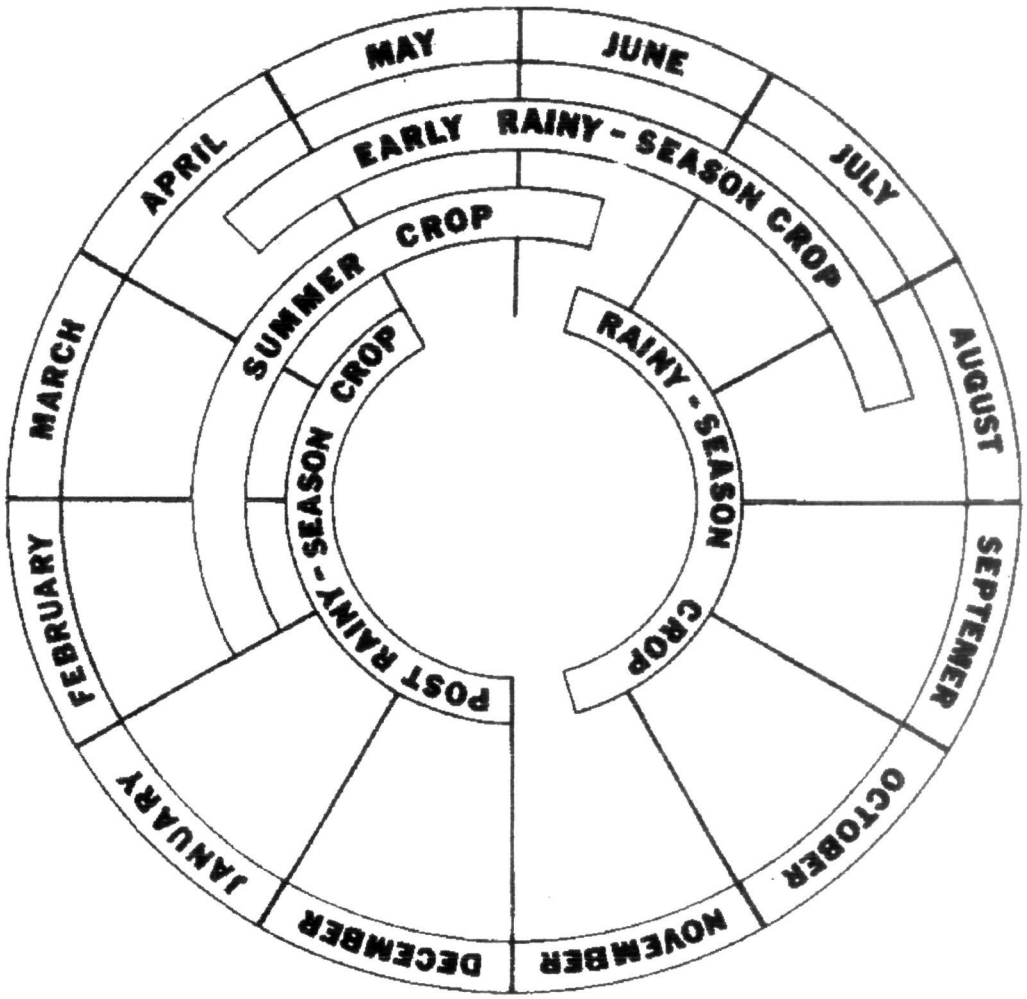


Fig. 9. Groundnut cropping seasons in northern Karnataka and overlapping of the seasons for perpetuation of *P. arachidis*.

Plate 6a. Off-season survival of uredospores of *P. arachidis* on self sown/voluntary groundnut plants.

Plate 6b. Close-up view of off-season survival of uredospores of *P. arachnids* on self sown/voluntary groundnut plants.

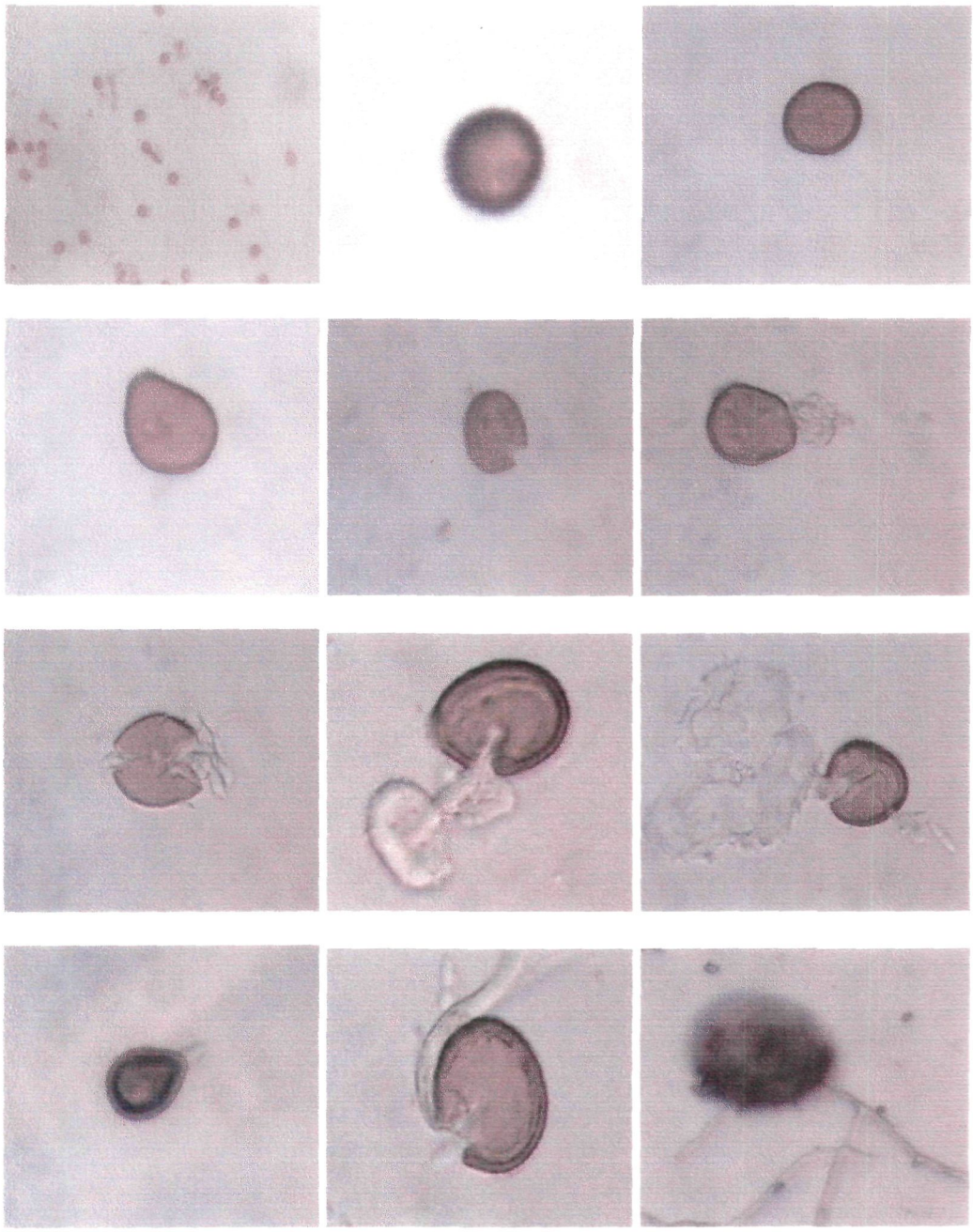


Plate 7 . Microscopic view of uredospores of *P. arachidis* and different stages of germination.

The results revealed that, maximum germination (90.81%) of uredospores was recorded after 12 h when stored at 25°C. Higher temperatures of 30°C recorded lower germination percentage (27.69%) at 12 h) indicating that temperature above 25°C may not be congenial for uredospore germination.

Effect of incubation period on germination of uredospores of *P. arachidis*

The effect of incubation period on germination of uredospores was studied in the laboratory and the results indicated that, the germination of uredospores started early (25% at 4 hr) and it appeared that with increase in time there was an increase in per cent germination of uredospores. The germination per cent of 70.55 was recorded after 8 h of incubation. However, maximum germination (93.05%) was observed after 48 h of incubation (Table 14).

Effect of humidity in relation to disease development

A pot culture experiment was conducted under glass house to study the humidity required for the infection and further development of the pathogen during *kharif* 2003 and results are presented in the Table 15. The data indicated that, minimum period of 48 h of higher humidity (85-90%) was required for infection (56.06%). Further, it was observed that 72 h of humidity was optimum for maximum infection (98.05%) and more number of rust pustules (68.86). However, there was no infection and number of rust pustules up to 24 h of incubation at higher relative humidity.

Table 14: Effect of incubation period on germination of uredospores of *P. arachidis*

Sl. No.	Incubation period (h)	Per cent germination of uredospores
1	4	25.00
2	8	70.55
3	12	82.60
4	24	88.40
5	48	93.05
6	72	82.85

Table 15: Effect of relative humidity and incubation period on percent disease index and number of pustules of rust of groundnut.

Sl. No.	Incubation period (hr)	Per cent disease index	Number of rust pustules
1	6	0.00	0.00
2	12	0.00	0.00
3	24	0.00	0.00
4	48	56.06	27.31
5	72	98.05	68.86

Effect of age of plant in relation to infection of *P. arachnids*

Age of the plant is important for the development of disease. A study was conducted to find out the susceptible stage of the groundnut crop for maximum rust infection (Table 16).

The results revealed that, plants of all age groups ranging from 10-90 days were found susceptible to rust infection. The disease development started at 10 days (80.56%), increased gradually but there was a difference in the intensity of rust. The maximum intensity of rust (99.01%) was observed on 50 days old plants followed by 40 days (98.48%) and 30 days (98.34%). The disease intensity was decreased from 96.42 to 90.41 per cent after 60 to 80 days, respectively.

Effect of date of sowing on the incidence of rust of groundnut.

Field experiments as explained in Material and Methods were conducted during *kharif* season of 2002 and 2003 with seven sowing dates starting from 1st June to 1st September at fortnightly intervals at Regional Agricultural Research Station, Raichur to find out the best sowing date for least incidence of rust on susceptible variety KRG-1. The results are presented in Table 17 and Fig. 10.

During 2002, there was a significant difference in the incidence of rust at different sowing dates. The per cent disease index varied from 30.37 to 96.30 per cent. The crop sown during 1st June was found significantly superior to all sowing dates. The PDI of 30.37 per cent was observed on 1st June followed by 16th June (33.40%) and 1st July (38.16%). While, the highest

Table 16: Age of the plant in relation to percent disease index of groundnut rust caused by *P. arachidis*.

Sl. No.	Age of the plant (days)	Percent Disease index (PDI)
1	10	80.56
2	20	86.11
3	30	98.34
4	40	98.48
5	50	99.01
6	60	96.42
7	70	91.85
8	80	91.60
9	90	90.41

Table 17: Effect of date of sowing on per cent disease index of rust, pod and haulm yield of groundnut during *kharif* 2002-03

Sl. No.	Sowing date	Per cent disease index (PDI)			Pod yield (q/ha)			Haulm yield (q/ha)		
		K-02	K-03	Mean	K-02	K-03	Mean	K-02	K-03	Mean
1	1st June	30.37 (33.42)	31.11 (33.90)	30.74	14.86	13.28	14.07	20.52	21.22	20.87
2	16th June	33.40 (35.30)	34.12 (35.73)	39.18	12.85	12.52	12.69	18.68	19.10	18.89
3	1st July	38.16 (38.12)	39.10 (38.65)	67.78	12.11	11.58	11.85	16.51	17.88	17.20
4	16th July	95.56 (78.11)	96.30 (79.31)	95.93	12.01	11.39	11.70	15.24	15.41	15.33
5	1st August	97.04 (79.99)	98.52 (82.39)	97.78	11.85	10.56	11.21	15.21	15.01	15.11
6	16th August	96.30 (79.05)	94.81 (77.18)	95.56	11.65	10.89	11.27	16.08	15.23	15.66
7	1st Sept.	85.93 (68.01)	91.11 (72.74)	88.52	12.01	11.95	11.98	16.54	15.68	16.11
	S.Em±	1.62	1.38	--	0.91	0.60	--	1.03	0.71	--
	CD at 5%	4.26	4.20	--	2.73	1.81	--	3.09	2.11	--

*Values in parenthesis are angular transformed values

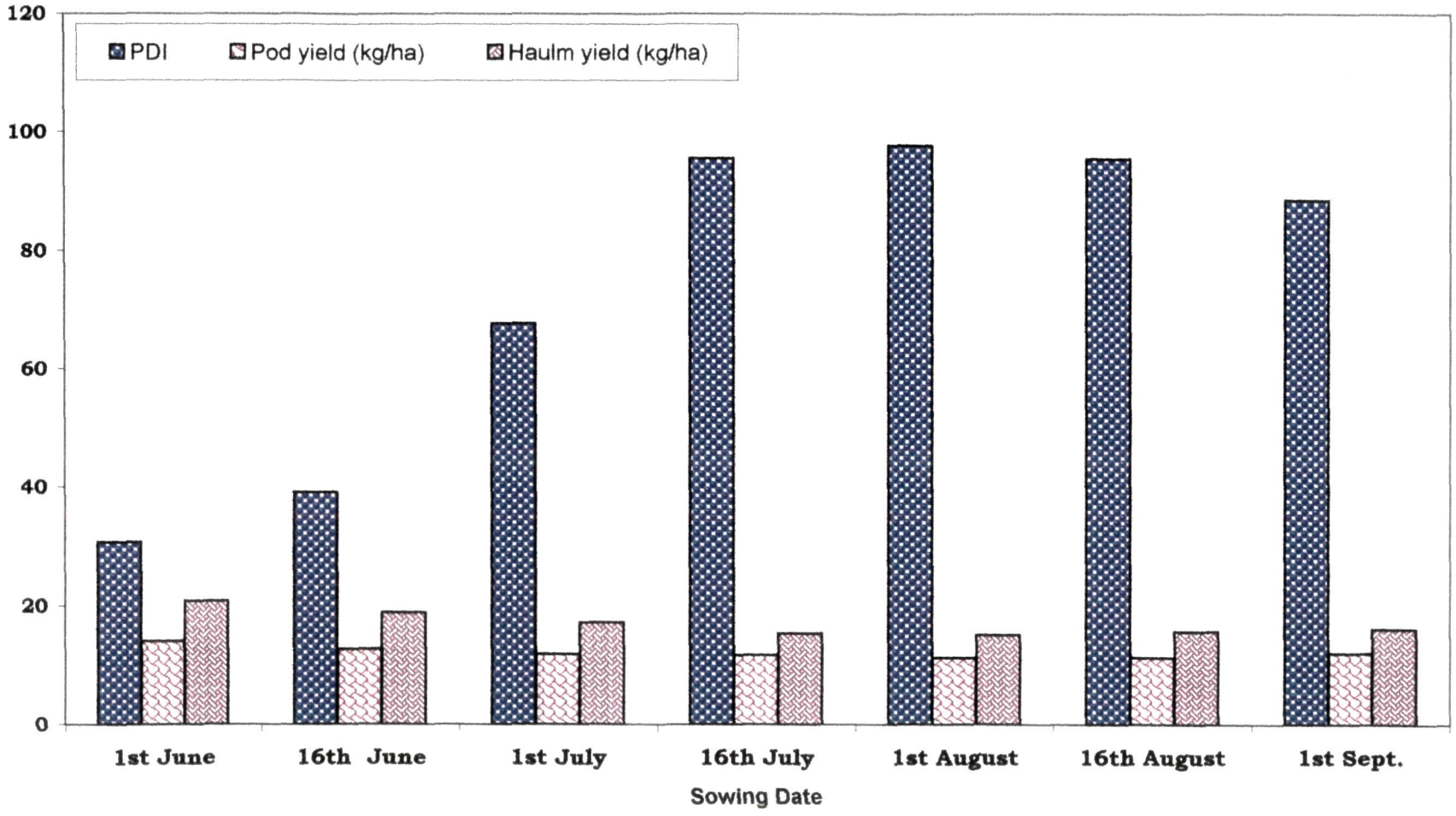


Fig. 10. Effect of date of sowing on percent disease index of rust, pod and haulm yield of groundnut during *kharif* 2002-03

PDI was recorded on crop sown on 1st August (97.04%) and was found on par with PDI of the crop sown on 16th July (95.56%) and 16th August (96.30%).

Similar results were obtained during 2003 also. The least incidence of 31.11 per cent was recorded on crop sown on 1st June, while maximum PDI on crop sown on 1st August (98.52%). The mean PDI ranged from 30.74 to 97.78 per cent. The mean data of two years indicated the same trend of results as observed in individual years with respect to per cent disease index of rust.

The yield of groundnut in different sowing dates differed significantly during both the years. Significantly higher yields (14.86 q/ha and 13.28 q/ha) were obtained in 2002 and 2003, respectively when compared to other treatments except yields obtained on 16th June. The mean yield data revealed that, highest mean yield of 14.07 q/ha was obtained in crop sown on 1st June followed by 16th June (12.69 q/ha) and 1st July (11.85 q/ha).

The different sowing dates have significant effect on haulm yield of groundnut. The crop sown on 1st June recorded maximum haulm yield of 20.52 q/ha and 21.22 q/ha during 2002 and 2003, respectively which were found significantly different from haulm yields obtained in other sowing dates. Minimum haulm yield of 15.21 q/ha and 15.01 q/ha were recorded on crop sown on 1st August during 2002 and 2003 respectively. The mean of two years showed maximum haulm yield of 20.87 q/ha when the crop was sown on 1st June followed by 16th June (18.89 q/ha) and1st July (17.20 q/ha).

Aerobiology

As a part of epidemiology of disease, aerobiological studies such as trapping of uredospores (Plate 8a & 8b), first appearance of uredospore load and disease, and development of spore load and progress of disease were carried out during 2002 and 2003 (Table 18 and 19).

Trap nursery trial

Trap nursery experiment was conducted to know the incidence of the disease, movement of uredospores of *P. arachidis* and time lag between spore catch in spore trap and disease incidence in trap nurseries at different locations during *kharif* 2002 and 2003.

Possible pathway of *P. arachidis*

The disease appearance was first noticed in Raichur on 5-8-2002 followed by Gangavati and Gulbarga on 10-09-2002, Bijapur (12-9-2002), Hagari (17-09-2002), Bidar (18-9-2002), Annigeri (20-9-2002), Dharwad (22-9-2002) and Arabhavi (28-9-2002) during 2002 (Table 18).

During 2003, the appearance of disease followed same trend as observed during 2002 (Table 18). The disease was first noticed in Raichur (1-8-2003), Gangavati (24-8-2003), Gulbarga (6-9-2003), Bijapur (10-9-2003), Hagari (12-09-2003), Bidar (14-9-2002), Annigeri (15-9-2003), Dharwad (20-9-2002) and Arabhavi (22-9-2002).

Based on the above information, the possible movement of uredospores of *P. arachidis* was traced and depicted in Fig. 11 & 12.

Table 18: Time lag between spore catch to incidence of rust of groundnut caused by *P. arachidis* in trap nursery.

Sl. No.	Place	*Kharif* 2002				*Kharif* 2003			
		Date of sowing	Date of spore catch in spore trap	Date of disease appearance	Incubation period (days)	Date of sowing	Date of spore catch in spore trap	Date of disease appearance	Incubation period (days)
1	Annigeri	24-6-2002	--	20-9-2002	--	10-6-2003	6-9-2003	15-9-2003	9
2	Arabhavi	20-6-2002	20-9-2002	28-9-2002	8	12-6-2003	14-9-2003	22-9-2003	8
3	Bidar	25-6-2002	10-9-2002	18-9-2002	8	12-6-2003	7-9-2003	14-9-2003	7
4	Bijapur	26-7-2002	--	12-9-2002	--	10-7-2003	--	10-9-2003	
5	Dharwad	20-6-2002	16-9-2002	22-9-2002	6	15-6-2003	--	20-9-2003	--
6	Gangavati	20-6-2002	2-9-2002	10-9-2002	8	12-6-2003	--	24-8-2003	
7	Gulbarga	19-7-2002	-	10-9-2002	--	10-7-2003	--	6-9-2003	-
8	Hagari	18-6-2002	10-9-2002	17-9-2002	7	10-6-2003	4-9-2003	12-9-2003	8
9	Raichur	20-6-2002	30-7-2002	5-8-2002	6	18-6-2003	25-7-2003	1-8-2003	7

Table 19: Development of weekly spore load, disease incidence and meteorological parameters associated during 2002 and 2003 at RARS, Raichur.

Std. week	Stage of crop	Weekly spore load	Weekly rust PDI	Temperature (° C)		Rel. Humidity (%)		Rainfall (mm)
				Max.	Min.	Mor.	Eve.	
***Kharif*, 2002**								
28	19-25	0	0	33.8	22.6	84.3	59.5	12.2
29	26-31	0	0	34	22.7	85.3	60.4	28
30	32-38	0	0	35.1	23	84.9	49.7	1.2
31	39-45	2.20	12.11	33.8	23.9	87.3	64.1	20
32	46-52	4.42	15.20	29.1	21.8	89.9	75.9	79.8
33	53-59	6.57	28.78	32.6	22.9	79.7	52.1	0
34	60-66	15.43	40.28	33.2	22.5	78.7	45.3	4
35	67-73	12.43	52.4	34.3	24	73	49.4	3.4
36	74-81	19.86	61.86	34.3	22.6	78.6	43.6	28.2
37	82-88	17	72.21	34.6	23.4	72.6	45.4	0
38	89-95	23.14	76.56	33.6	22.4	82	48.1	81
39	96-102	35.2	88.2	35.2	23.6	75.9	36.3	0
***Kharif*, 2003**								
28	17-23	0	0	34.1	22.8	85.5	55.1	14.4
29	24-30	0	0	36.9	24.2	73.4	49.6	4.4
30	31-37	1.03	0	33.1	23.6	84.6	55	1.6
31	38-44	1.61	13.25	34.4	22.9	79.6	55	10.8
32	45-51	3.14	17.58	31.7	23	82.6	60	30.2
33	52-58	15.28	30.41	34.8	23.5	75.8	43	4.4
34	59-65	14.86	44.45	30.5	22.2	87.1	66	73.2
35	66-72	22.71	60.02	33	22.8	78	53	15.2
36	73-79	18.2	69.51	33.4	22.2	77	46	0
37	80-86	12.6	76.82	34.3	21.9	72.9	44	12.4
38	87-93	12	79.50	34.2	23.8	71.6	41	0
39	94-100	21.14	80.1	31.3	22.6	89.6	60	66.6

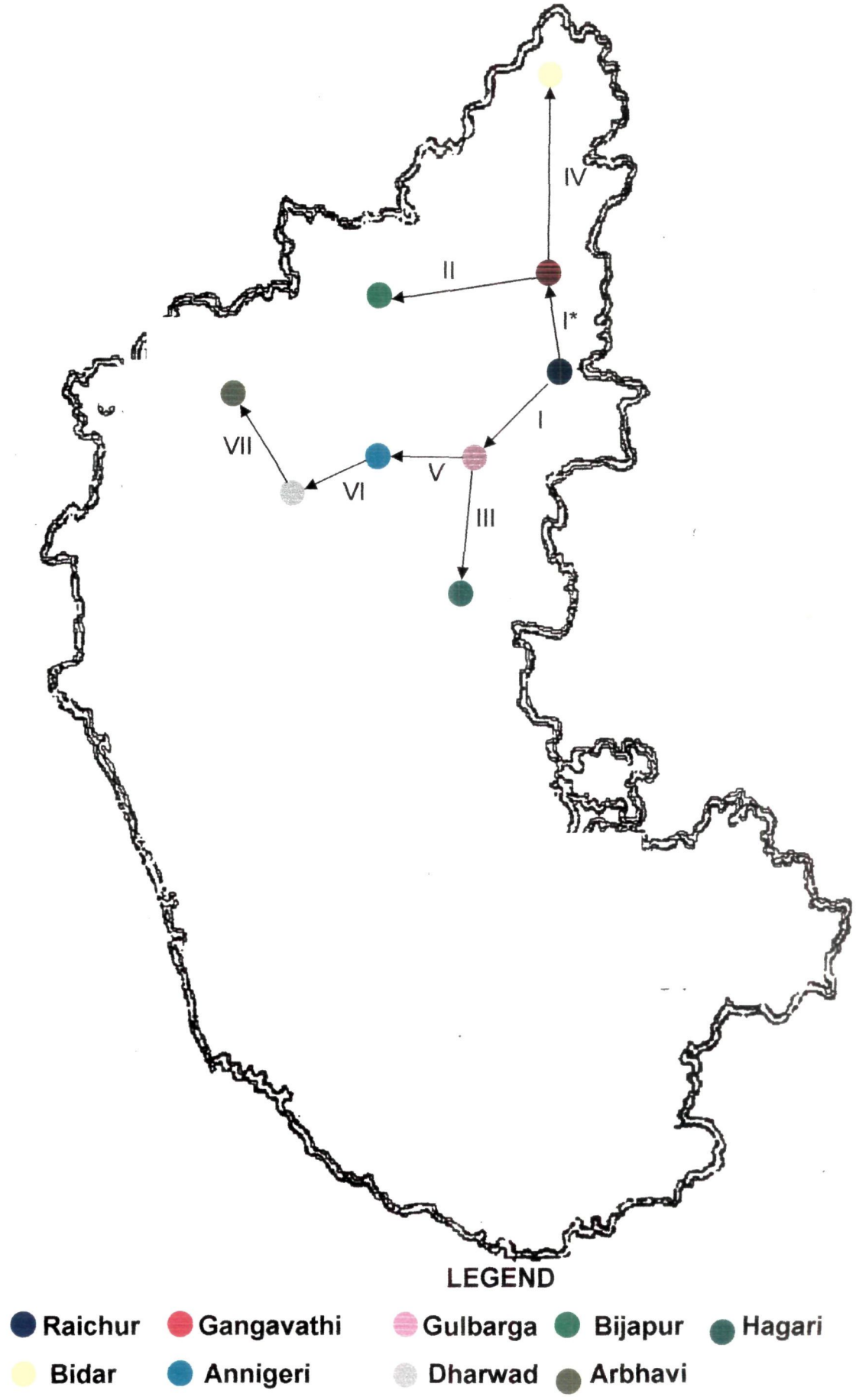


Fig. 11. Probable pathway of *P. arachidis* in northern Karnataka during *kharif* 2002

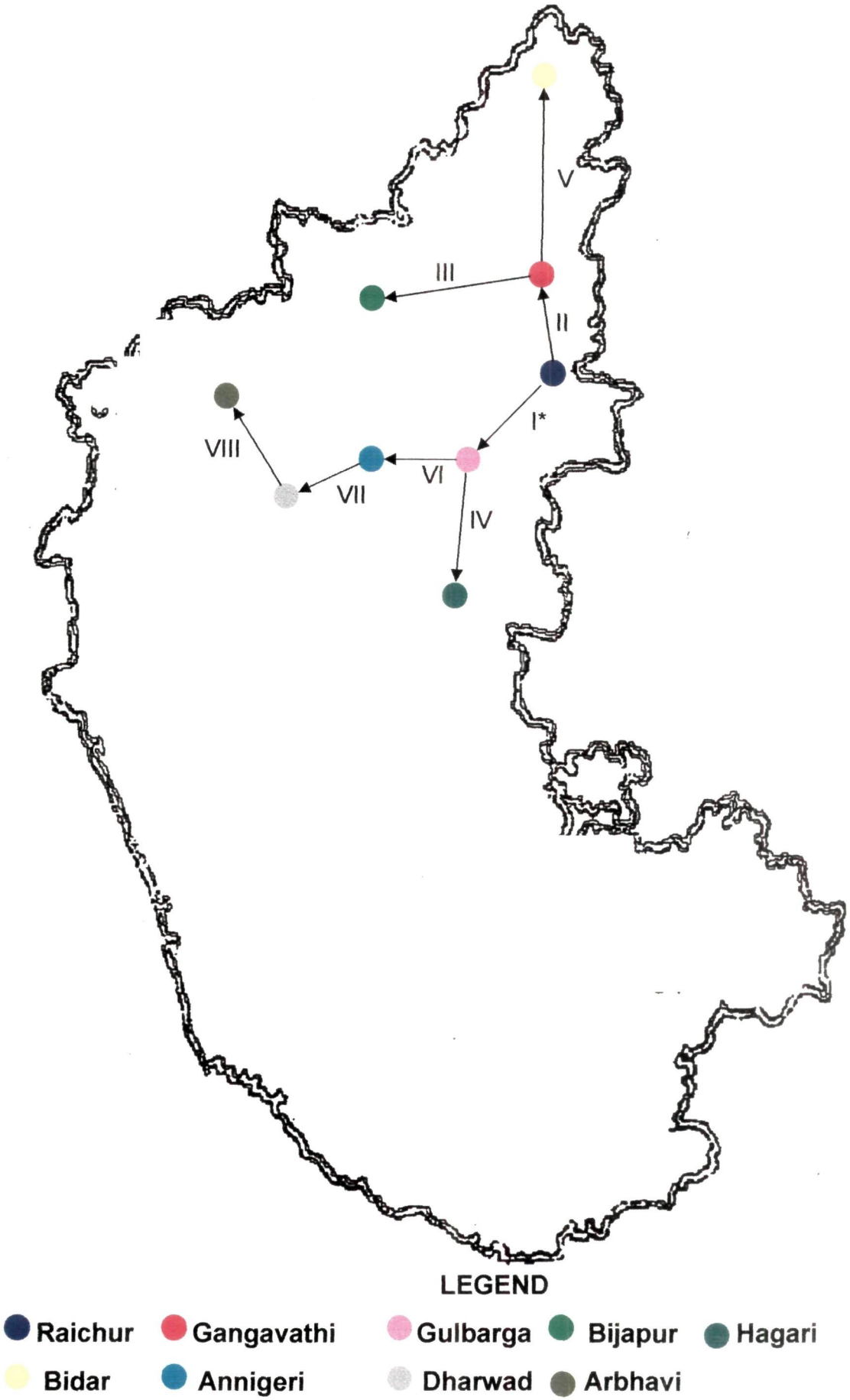


Fig. 12. Probable pathway of *P. arachidis* in northern Karnataka during *kharif* 2003

Plate 8a. Trapping of uredospores by mounting aeroscope in the groundnut field.

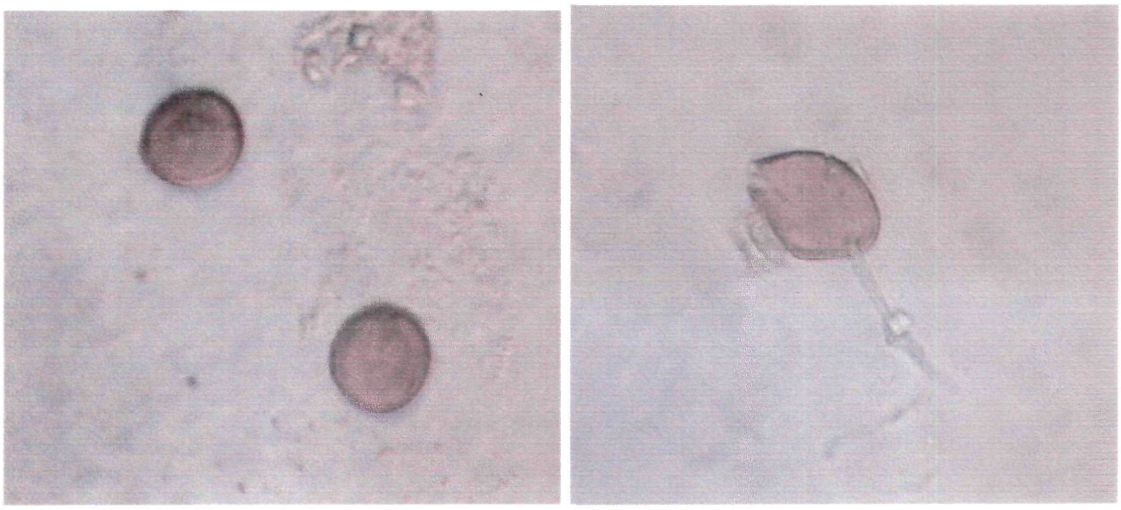


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Plate 8b. Microscopic view (40X) of trapped uredospores (1) on vaseline coated glass slide and germination of uredospore (2).

Effect of weather factors on development of spore load of *P. arachidis*

The study on development of spore load of *P. arachidis* was carried out at RARS, Raichur and presented on weekly average in terms of standard week with meteorological data (Table 19 & Fig. 13a and 13b).

Air sampling was carried out during 2002 indicated that, the first appearance of spore load in the atmosphere was recorded after 40 days of sowing i.e., on 30-7-2002. The spore load gradually increased and reached peak of 35.20 during 39th standard week. During previous meteorological week, weather conditions such as rainfall of 81 mm, with mean temperature ranged between 22.40°C to 33.6°C and relative humidity of 48.1 to 82.00 per cent were prevailed (Table 19). Further, data indicated that more number of uredospores were present during the month of August and September.

During 2003, the first appearance of spore load was observed after 37 DAS (38th std. week) and gradually increased from 1.03 to maximum of 22.71 during 35th standard week. During previous week, the maximum temperature of 30.5°C and minimum temperature of 22.2°C with morning and evening relative humidity 87.1 and 66 per cent, respectively and rainfall of 73.20 mm was noticed (Table 19). Similarly, high spore counts were recorded during August-September as observed in 2002.

Correlation and multiple linear regression analysis between spore load of *P. arachidis* and weather parameters

An attempt was made to establish the relationship between weather factors *Viz.* minimum and maximum temperature, morning and evening relative humidity and rainfall with spore load of *P. arachidis* through

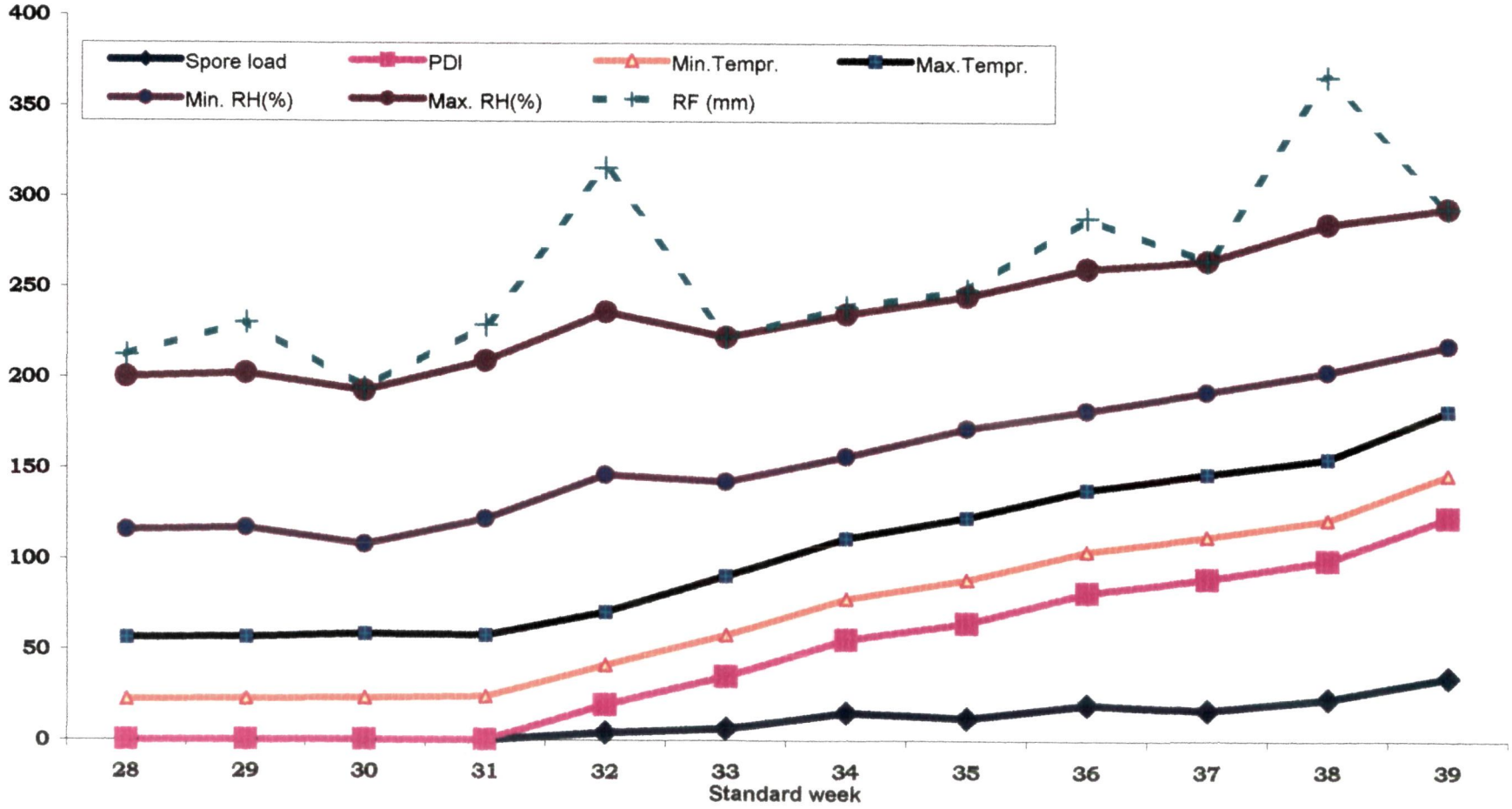


Fig. 13a. Development of weekly spore load, disease incidence of rust and meteorological parameters associated during *kharif* 2002.

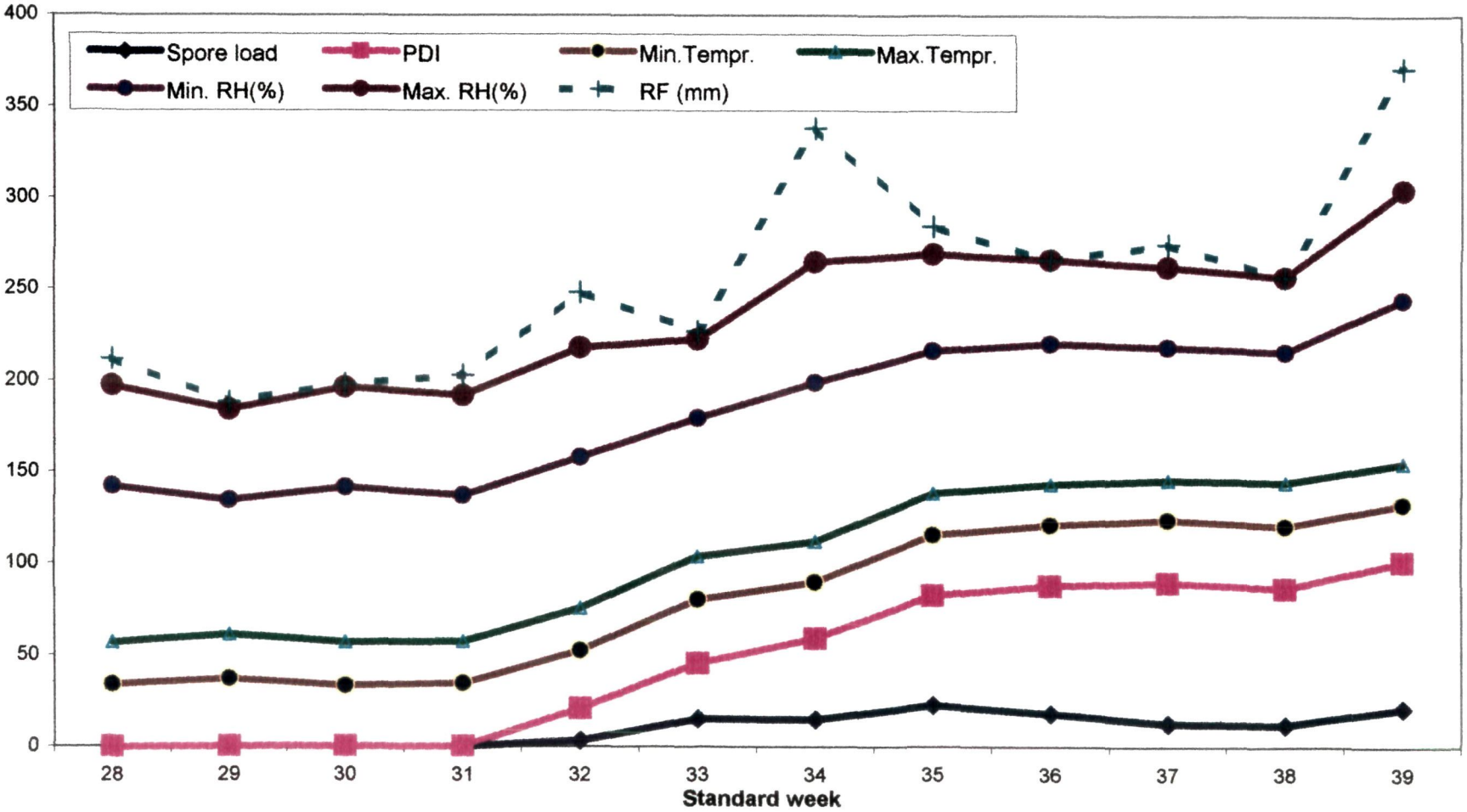


Fig. 13b. Development of weekly spore load, disease incidence of rust and meteorological parameters associated during *kharif* 2003.

correlation and multiple linear regression analysis. The step down procedure was adopted to include most significant weather parameters in the multiple regression analysis.

The relationship between spore load of *P. arachidis* and weather factors during 2002 (Table 20) indicated a higher negative correlation between morning and evening relative humidity with a correlation coefficient of -0.76 and -0.66, respectively. During 2003, the correlation coefficient between spore load and weather was non significant but the rainfall indicated positive relation whereas the temperature and relative humidity were negatively related. However, the pooled analysis indicated that temperature and relative humidity were negatively correlated, while rainfall had positive correlation with development of spore load of *P. arachidis*.

The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is, $Y = 224.30-2.21X_1-1.73X_2-0.76X_3-0.84X_4+0.21X_5$. With the step down procedure, only one variable *i.e.*, minimum temperature (X_2) was eliminated and final equation fitted to the data is $Y = 170.48-2.04X_1-0.46X3-1.14X_4+0.25X_5$ (Table 21).

Where,

X_1= Maximum Temperature (°C), X_2= Minimum Temperature (°C), X_3 = Relative humidity (%) morning, X_4 = Relative humidity (%) evening and X_5 = Rainfall (mm).

Table 20: Correlation between weekly spore load of *P. arachidis* and weather parameters

Sl. No.	Weather parameter	Correlation coefficient (r)	
		2002	2003
1	Maximum Temperature (°C)	0.14	-0.41
2	Minimum Temperature (°C)	0.29	-0.45
3	Relative humidity (%) morning	-0.76*	-0.03
4	Relative humidity (%) evening	-0.66*	-0.12
5	Rainfall (mm)	0.03	0.34

- Significant at 1% probability level

Table 21: Multiple linear regression of spore load of *P. arachidis* in relation to weather parameters

Year.	Constant (A)	X_1	X_2	X_3	X_4	X_5	R^2
All weather factors	224.30	-2.21	-1.73	-0.76	-0.84	0.21	0.66
Significant weather factors	170.48	-2.04	--	-0.46	-1.14	0.25	0.63

X_1= Maximum Temperature (°C)

X_2= Minimum Temperature (°C)

X_3 = Relative humidity (%) morning

X_4 = Relative humidity (%) evening

X_5 =Rainfall (mm)

This explains that when there is increase of one unit of maximum and minimum temperature, morning and evening relative humidity and rainfall, the spore load is lowered by 2.21, 1.73, 0.76, 0.84 and increased by 0.21 units respectively. The weather factors influence the spore load of *P. arachidis* to the extent of 66 per cent. When the significant weather factors were analyzed with every increase of one unit of minimum temperature, morning and evening relative humidity and rainfall, the per cent disease incidence is lowered by 2.04, 0.46, 1.14 and increased by 0.25 units, respectively. The weather factors influence the spore load to the extent of 63 per cent.

Effect of weather parameters on development and spread of disease

The knowledge of weather conditions predisposing for the development and spread of disease is important to organize Agro-Advisary Services (AAS) for the farmers to take up timely control measures (Table 19 & Fig. 13a and 13b).

During 2002, the rust symptoms were first observed on 31st standard week when the crop was at 46 DAS. The severity increased slowly and reached the incidence as high as 88.20 per cent when the crop was at pre-harvesting stage. During the previous week, maximum temperature of 33.6°C and minimum temperature was 22.40°C with morning relative humidity of 82.00 per cent followed by 81 mm rainfall.

During 2003, the rust symptoms were first observed on 31st standard week when the crop was at 44 DAS. The rainfall of 1.6 mm with minimum temperature of 23.6 and maximum temperature of 33.1°C, morning relative humidity of 84.6 per cent was prevailed during previous week. Severity

increased slowly and reached maximum incidence of 80.10 per cent when the crop was at harvesting stage. The favourable conditions such as rainfall of 66.6 mm with 89.6 per cent morning relative humidity were noticed during that standard week.

The data on both the years indicated 31st standard week was highly favourable for first appearance of disease. The weather factors played an important role in the initiation and further spread of disease. It gives information to design supervisory control measures of disease in order to get expected pod and fodder yield.

Correlation and multiple linear regression analysis between severity of rust and weather parameters

The analysis was made to establish the relationship between weather factors *viz.,* maximum and minimum temperature, morning and evening relative humidity and rainfall with per cent disease index of disease in highly susceptible variety KRG-1 through correlation and multiple linear regression analysis. Further, step down regression procedure was adopted to include most significant weather parameters in the multiple regression analysis.

The relationship between rust PDI and weather factors during 2002 indicated a higher negative correlation between morning and evening relative humidity with a correlation coefficient of -0.74 and -0.76, respectively (Table 22). During 2003, the correlation coefficient between per cent disease index and weather was non significant but the rainfall (0.25) indicated positive relation whereas the temperature and relative humidity were negatively related (Table 23).

Table 22 : Correlation between per cent disease index of rust and weather parameters

Sl. No.	Weather parameter	Correlation coefficient (r)	
		2002	2003
1	Maximum Temperature (°C)	0.18	-0.33
2	Minimum Temperature (°C)	0.28	-0.49
3	Relative humidity (%) morning	-0.74*	-0.19
4	Relative humidity (%) evening	-0.76*	-0.28
5	Rainfall (mm)	0.01	0.25

* Significant at 1% probability levels

Table 23: Multiple linear regression of per cent disease index of rust of groundnut in relation to weather parameters.

Year.	Constant (A)	X_1	X_2	X_3	X_4	X_5	R^2
All weather factors	851.45	-11.44	-3.37	-1.62	-4.56	0.73	0.80
Significant weather factors	747.05	-11.12	--	-1.06	-5.15	0.82	0.79

X_1= Maximum Temperature (°C)

X_2= Minimum Temperature (°C)

X_3 = Relative humidity (%) morning

X_4 = Relative humidity (%) evening

X_5 =Rainfall (mm)

The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is, Y = 851.45-11.44X_1-3.37X2-1.62X3-4.56X4+0.73X5. With the step down procedure, only one variable *i.e.*, minimum temperature (X_2) was eliminated and final equation fitted to the data is Y = 747.05-11.12X1-1.06X3-5.15X4+0.82X5.

This explains that when there is increase of one unit of maximum and minimum temperature, morning and evening relative humidity and rainfall, the per cent disease incidence is lowered by 11.44, 3.37, 1.62, 4.56 and increased by 0.73 units respectively. The weather factors influence the disease incidence in KRG-1 to the extent of 80 per cent. When the significant weather factors were analysed with every increase of one unit of minimum temperature, morning and evening relative humidity and rainfall, the per cent disease incidence is lowered by 11.12, 1.06, 5.15 and increased by 0.25 units, respectively. The weather factors influence the disease incidence in KRG-1 to the extent of 79 per cent.

Disease prediction models

Weather factors play an important role in disease development when the vulnerable host and virulent pathogen coincide in a situation. An attempt was made to predict the severity of rust using logistic model.

The disease severity was recorded at weekly interval on susceptible variety KRG-1 during 2002 and 2003 (Table 19). Since, the disease progress curve behaved in a same manner during both *kharif*, 2002 and 2003 (Fig. 14), the logistic method was used to develop disease prediction models. The values were calculated and the models were developed to predict the severity

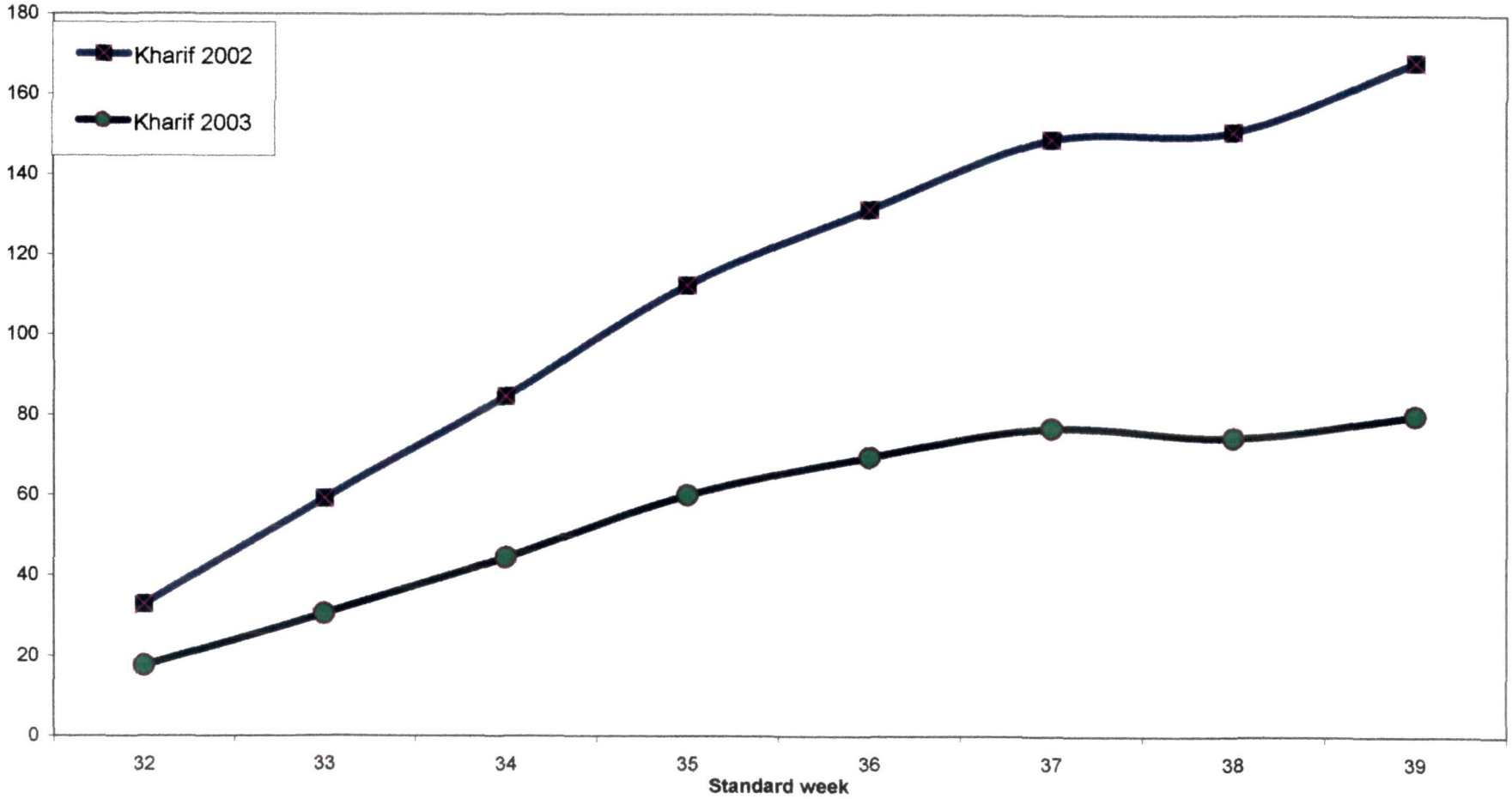


Fig. 14. Disease progess of groundnut rust caused by *P. arachidis* during *kharif* 2002 and *kharif* 2003 on KRG-1 variety at RARS, Raichur.

of rust. Observed and predicted disease severity of rust of groundnut during Kharif, 2002 and 2003 are given Table 24 and Fig. 15.

***Kharif*, 2002**

The calculated values for a and b are, a = 0.952 and b = –0.193.

Hence, the model for Kharif, 2002 is,

$$\hat{Y}_t = \frac{100}{1 + e^{0.952-0.193\ t}} \quad \text{with } r = 0.98.$$

***Kharif*, 2003**

The calculated values for a and b are, a = 1.157 and b = –0.234.

Hence, the model for Kharif, 2003 is,

$$\text{and } \hat{Y}_t = \frac{100}{1 + e^{\ 1.157-0.234\ t}} \quad \text{with } r = 0.99.$$

The models had high coefficient of determination values with 98 and 99 per cent for *kharif*, 2002 and 2003, respectively.

STANDARDISATION OF INOCULATION METHODS

Different methods of inoculation with matured viable uredospores of *P. arachidis* were evaluated to find out most effective one for understanding the slow rusting mechanism in groundnut varieties under artificial conditions as detailed in 'Material and Methods' and the results obtained are presented in Table 25.

The results revealed that, all the methods of inoculation were effective in causing the disease with severity ranging from 47.70 to 74.07 per cent. Of the seven methods of inoculation tried during 2002, stapler method of inoculation was found significantly superior over all other methods. The

Table 24: Observed and predicted PDI of rust of groundnut caused by *P. arachidis* during the progression of disease for *Kharif*, 2002 and 2003

Time Interval	Per cent disease index			
	Kharif, 2002		*Kharif*, 2003	
	Observed	Predicted	Observed	Predicted
1	12.11	31.89	13.25	28.44
2	15.20	36.22	17.58	33.43
3	28.78	40.78	30.41	38.82
4	40.28	45.52	44.45	44.50
5	52.40	50.33	60.02	50.33
6	61.86	55.16	69.51	56.15
7	72.21	59.84	76.82	61.80
8	76.56	64.39	79.50	67.16
9	88.20	68.68	80.10	72.10

Coefficient of determination is 0.95 and 0.99 for *kharif*, 2002 and 2003, respectively

Table 25: Effect of different inoculation methods for obtaining maximum incidence of groundnut rust caused by *P. arachidis*

Sl. No.	Method of Inoculation	Latent Period (days)*	Per cent Disease Index (PDI) **
1.	Carborandum application + Dusting	8.50	57.20 (49.48)
2.	Cotton swabbing	10.50	47.70 (43.94)
3.	Dusting	8.50	62.13 (51.86)
4.	Leaf dip inoculation	8.50	48.40 (44.16)
5.	Needle application	10.25	60.13 (50.78)
6.	Spraying	8.25	64.50 (53.43)
7.	Stapler method	7.50	74.07 (59.47)
8.	Control	10.25	11.11 (19.47)
	S. Em ±	0.39	0.56
	C.D. at 1%	1.56	2.19

*Values in parenthesis are angular transformed values.

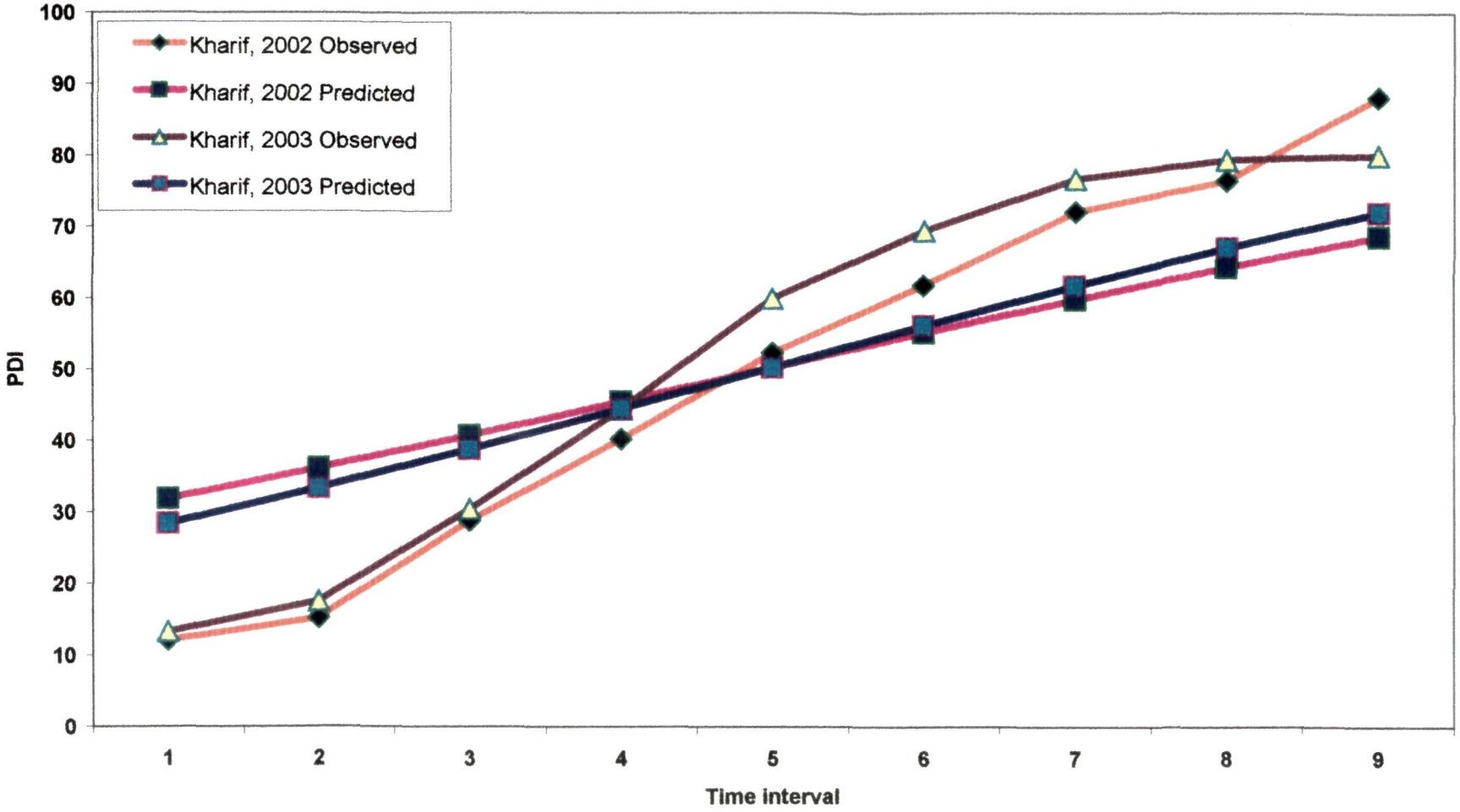


Fig. 15. Observed and predicted per cent disease index of rust of groundnut caused by *P. arachidis* during the progression of disease for *Kharif* 2002 and 2003

latent period was 7.50 days with the highest PDI of 74.07. Whereas, spraying of uredospores was next best method with the latent period of 8.25 days and PDI of 64.50 per cent. Dusting was also effective by recording 62.13 per cent disease index and 8.50 days latent period. However, cotton swabbing was found to be the in-effective method of inoculation by recording significantly least disease index (47.70%) with highest incubation period (10.50 days).

HISTOLOGICAL AND HISTOCHEMICAL STUDIES

Histological studies

The microtome sections of healthy leaves of groundnut revealed that, thick and intact epidermal layer with cylindrical palisade and sound spongy parenchyma cells. Whereas, the section of diseased leaves showed more damage to leaf structure. The epidermis was thick but not intact. The cells of leaf were completely destroyed because of formation of pustules (Plate 9).

Histochemical studies

The histochemical studies for localization of insoluble polysaccharides, nucleic acids and proteins in healthy and diseased were studied through microtome technique as explained in "Material and Methods" and the results are given in Table 26 (Plate 9).

Polysaccharides

The palisade and spongy parenchyma cells of healthy leaf showed medium (++) polysaccharides which were indicated by dark colour, while in diseased leaves palisade and spongy parenchyma cells showed less PAS (light purple colour) indicating low level (+) of polysaccharides.

Table 26: Histochemical parameters of healthy and rust affected leaves of groundnut variety KRG-1.

Sl. No	Type of stain	Epidermis		Palisade parenchyma		Spongy parenchyma	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
1	PAS	++	+	++	+	++	+
2	MBB	+++	+	+++	+	+++	+
3	Azure B	++	+	++	+	++	+

PAS : Periodic acid Schiffis for insoluble polysaccharides.

MBB : Mercuric bromophenol blue for total proteins.

Azure B : For nuclear acids (RNA and DNA).

Legend

+++ ------- Rich

++ ------ Medium

+ ------- Low

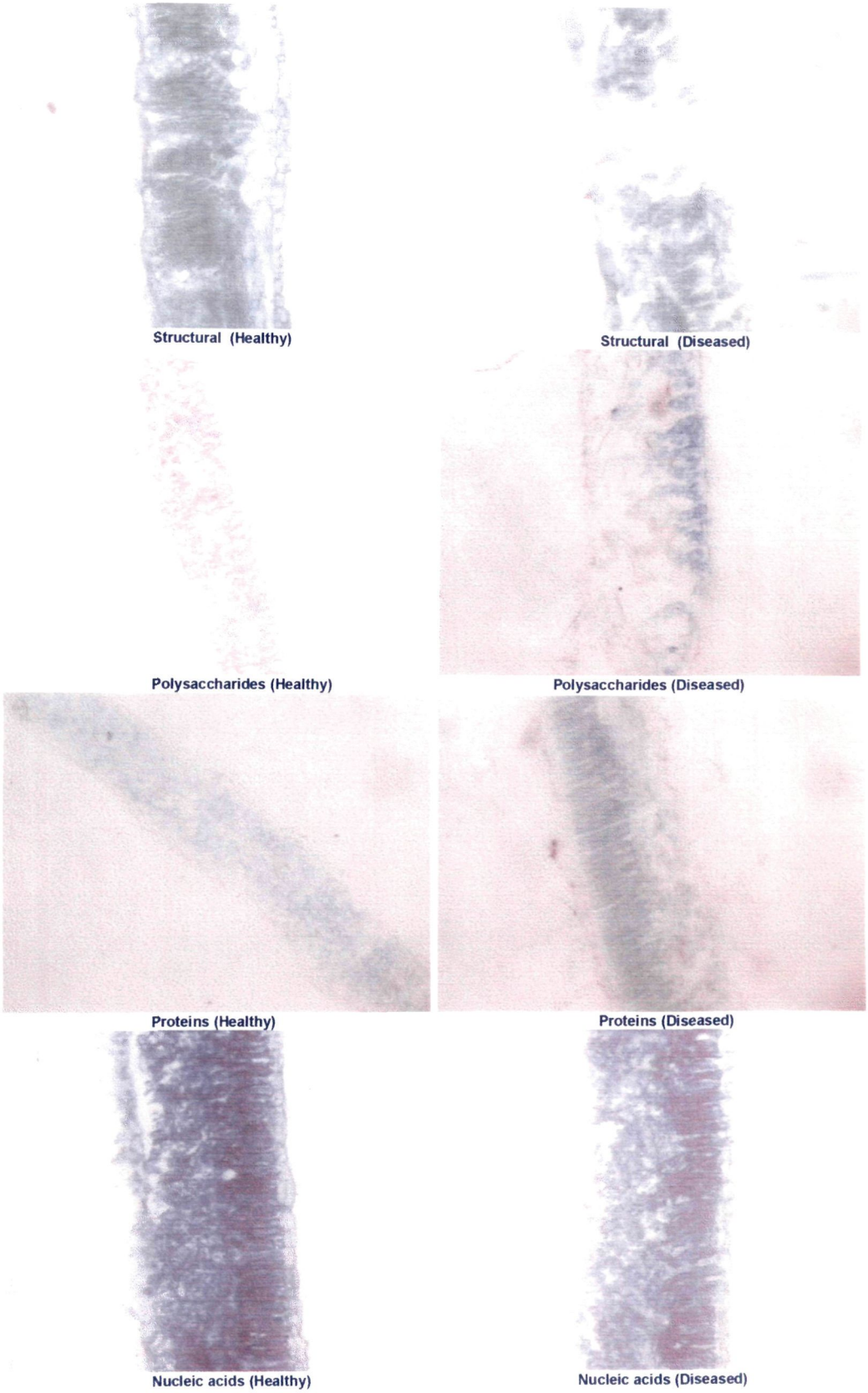


Plate 9. Histological and histochemical changes in healthy and *P. arachidis* infected leaves of groundnut.

Proteins

The microtome results showed that, palisade and parenchyma cells of healthy leaves were rich (+++) for Mercuric bromophenol blue (MBB) indicating more concentration of total protein which was indicated by dark blue colour. Whereas, the diseased cells showed low (+) total proteins by producing light blue colour with MBB.

Nucleic acids

The Azure B produced light blue stain with healthy microtome leaf sections of groundnut leaves indicating moderate concentration (++). Whereas, in the diseased leaves, palisade and spongy parenchyma cells exhibited low (+) concentration of nucleic acids particularly DNA (greenish blue) than RNA (Light blue).

The results indicated that, diseased leaves showed low (+)) concentration of all the molecules in palisade and spongy parenchyma cells. On the contrary, healthy leaves showed rich (+++) concentration of proteins and medium concentration of polysaccharides and nucleic acids.

MECHANISM OF RESISTANCE

Physiological basis of resistance

Histological parameters

In order to know the difference between resistant and susceptible varieties, cuticular thickness, epidermal cell thickness, and number of epidermal cells and stomata were studied as explained in "Material and Methods". The results of the findings are presented in Table 27 & Fig. 16.

Table 27: Histological parameters in resistant, moderately resistant and susceptible varieties of groundnut to rust caused by *P. arachidis*

Sl. No.	Variety	Cuticular thickness (µm)	Epidermal cell thickness (µm)	Number of epidermal cells / mm
1	Dh-22 (Red)	4.14	11.44	33.12
2	GPBD-4	4.31	11.98	32.01
3	K-134	3.56	10.32	34.08
4	R-8808	3.30	10.05	34.12
5	KRG-1	3.06	9.02	36.28
6	TMV-2	3.07	9.03	35.52
	S.Em±	0.12	0.27	0.51
	CD at 1%	0.50	1.05	2.05

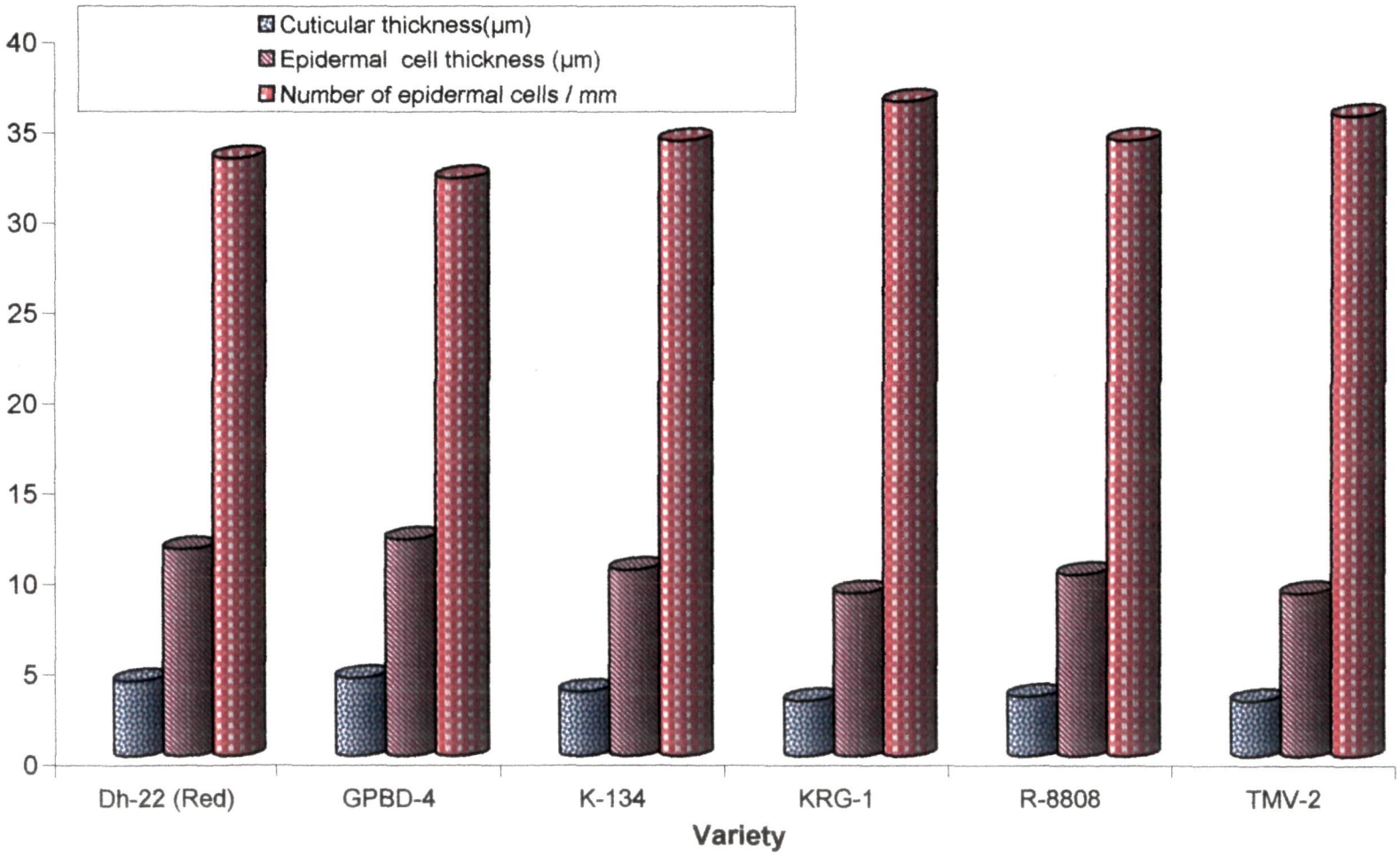


Fig. 16. Histological parameters in resistant, moderately resistant and susceptible varieties of groundnut against rust disease.

Cuticular thickness

The results revealed that, varieties differed significantly for their cuticle thickness of leaf. The highest cuticular thickness of 4.31 µm and 4.14 µm was observed in GPBD-4 and Dh-22 (Red), respectively and were found significantly different from rest of the varieties. Whereas, susceptible varieties, *viz.*, KRG-1 and TMV-2 recorded lesser cuticular thickness (3.06 µm and 3.07 µm, respectively) (Table 27).

Epidermal cell thickness

Both resistant and moderately resistant varieties recorded significantly higher epidermal cell thickness compared to KRG-1 and TMV-2. Among them, GPBD-4 had more epidermal cell thickness 11.98 µm followed by 11.44 µm in Dh-22 (Red). Further, moderately resistant genotypes *viz.*, K-134 and R-8808 showed significantly more epidermal cell thickness than susceptible genotypes (Table 27).

Number of epidermal cells

The results (Table 27) revealed that, resistant and moderately resistant varieties recorded lesser number of epidermal cells unlike cuticular and epidermal cell thickness. Among the varieties *viz.*, GPBD-4 was found significantly different in showing lesser number of epidermal cells (32.01 cells/mm) compared to rest of the varieties except Dh-22 (Red) (33.12 cells/mm), which is on par with GPBD-4. Further, moderately resistant *varieties* viz., R-8808 and K-134 recorded 34.12 and 34.08 cells/mm,

respectively and were significantly superior to susceptible variety KRG-1 (36.28 cells/mm), while TMV-2 recorded 35.52 cells/mm.

Number of stomata

The number of stomata were more in susceptible varieties than resistant and moderately resistant varieties on both adaxial and abaxial leaf surface (Table 28). On adaxial surface, stomatal frequency varied significantly among varieties. Both the varieties *viz.*, GPBD-4 and Dh-22 (Red) recorded stomatal number of 8.5/mm^2 of leaf and found significantly different from other varieties. Further, moderately resistant varieties *viz.*, R-8808 and K-134 showed significantly lesser stomatal number (13.00 and 12.75/mm^2, respectively) than KRG-1 (16.75/mm^2) and TMV-2 (16.00/mm^2).

The analysis of stomatal frequency on abaxial surface revealed that, the same trend of results as observed in case of adaxial surface. The least stomatal number was observed in GPBD-4 (10.86/mm^2) followed by Dh-22 (Red) (11.00/mm^2) and K-134 (11.75/mm^2). The variety TMV-2 recorded highest (16.21/ mm^2) number of stomata on abaxial leaf surface. Hence, it was found that stomatal number was comparatively more in abaxial leaf surface than on adaxial leaf surface in all varieties.

Size of stomata

On adaxial leaf surface stomatal length did not vary significantly among varieties. However, breadth of stomata was significantly differed in various varieties tested (Table 28). Though, there was no significant difference in length of stomata, resistant and moderately resistant varieties showed more length compared to susceptible varieties. The least length of 20.29 µm was

Table 28: Frequency and size of stomata in resistant, moderately resistant and susceptible varieties of groundnut to rust caused by *P. arachidis*.

Sl. No.	Variety	Number of stomata (mm^2)		Size of stomata			
		Adaxial surface	Abaxial surface	Adaxial surface		Abaxial surface	
				Length (µm)	Breadth (µm)	Length (µm)	Breadth (µm)
1	Dh-22 (Red)	8.50	11.00	20.79	8.49	19.01	6.23
2	GPBD-4	8.50	10.86	20.29	7.90	17.29	6.56
3	K-134	12.75	11.75	22.41	11.55	19.25	9.43
4	R-8808	13.00	12.86	20.10	12.82	20.16	10.55
5	KRG-1	16.75	16.00	25.43	14.74	26.12	15.77
6	TMV-2	16.00	16.21	24.71	15.56	25.97	14.96
	S.Em±	0.64	0.82	0.33	0.70	0.75	1.15
	CD at 1%	2.56	3.21	1.31	2.95	3.13	4.65

recorded in GPBD-4 followed by Dh-22(Red) (20.79 µm) and R-8808 (20.10 µm), while TMV-2 and KRG-1 recorded highest length of 24.71 µm and 25.43 µm, respectively.

As far as breadth of stomata on adaxial leaf is concerned, the varieties differed significantly. The varieties *viz.*, GPBD-4 and Dh-22(Red) recorded significantly lesser breadth of stomata (7.90 and 8.49 µm, respectively) compared to other varieties. Significantly lesser breadth of stomata was recorded by moderately resistant varieties *viz.*, R-8808 and K-134 (12.82 and 11.55 µm, respectively) when compared to KRG-1 and TMV-2 (14.74 and 15.56 µm, respectively).

On abaxial leaf surface, stomatal length and breadth varied significantly among varieties. Both resistant and moderately resistant varieties showed significantly lesser length and breadth compared to susceptible varieties. In case of GPBD-4 and Dh-22(Red), stomatal length of 17.29 µm and 19.01µm was recorded, respectively and were found on par with the length of stomata observed in moderately resistant varieties. However, susceptible varieties KRG-1 and TMV-2 recorded length of 26.12 and 25.97 µm, respectively which were significantly more than the length recorded in both resistant and moderately resistant varieties.

The results on breadth of stomata on abaxial leaf surface followed similar trend of results as observed in length on the adaxial surface. The least breadth of 6.23 and 6.56 µm was recorded on GPBD-4 and Dh-22(Red), respectively, while highest stomatal breadth was observed in KRG-1 (15.77

µm) and TMV-2 (14.96 µm). It is evident from the results that the length and breadth of stomata were found less on abaxial leaf surface than adaxial.

Wax content

Wettability of leaves is related to early infection process of *P. arachidis*. More amount of wax on leaf surface could not be easily wetted as wax is negatively charged particle. Thus, wax content of leaf is one of the important parameters of resistance. Hence, wax content was estimated in different varieties of groundnut.

The studies indicated that, wax content varied significantly among the varieties at different crop growth stages. At 25 and 50 DAS, resistant and moderately resistant varieties were significantly different from susceptible varieties in recording wax content and were on par with each other. However, on 75 DAS, resistant varieties recorded significantly more wax content than the wax content recorded in both moderately resistant and susceptible varieties (Table 29).

Further, it is evident from the results that wax content was increased from 25 DAS to 75 DAS in resistant ad moderately resistant varieties. Whereas, it was decreased with increase in age of the crop in susceptible varieties. The resistant variety, GPBD-4 recorded maximum wax content of 0.45 mg/dm^2 at 25 DAS, increased to 0.85 mg/dm^2 at 50 DAS and reached as high as 0.95 mg/dm^2 at 75 DAS. The variety Dh-22(Red) was next best in recording more wax as it recorded the range of 0.46 to 0.91 mg/dm^2 at 25 and 75 DAS, respectively. The least wax content of 0.16 mg/dm^2 was

Table 29: Changes in wax content in leaves of resistant, moderately resistant and susceptible varieties influenced by rust of groundnut caused by *P. arachidis*.

Sl. No.	Variety	Percent Disease Index (PDI)			Wax content (mg / dm^2)		
		25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS
1	Dh-22 (Red)	0	12.22	19.63	0.46	0.86	0.91
2	GPBD-4	0	0	14.81	0.45	0.85	0.95
3	K-134	0	13.70	30.74	0.31	0.49	0.59
4	R-8808	0	14.81	35.93	0.36	0.61	0.59
5	KRG-1	0	16.30	39.63	0.16	0.12	0.07
6	TMV-2	0	19.63	35.71	0.17	0.15	0.13
	S.Em±	--	--	--	0.05	0.06	0.08
	CD at 1%	--	--	--	0.24	0.24	0.35

observed in KRG-1 at 25 DAS and it was further decreased to 0.12 mg/dm^2 at 50 DAS to the least of 0.07 mg/dm^2 at 75 DAS.

Biochemical basis of resistance

The investigations on biochemical components of resistance against *P. arachidis* was carried out and results are presented in Table 30 and Fig. 17.

Sugars

The results indicated that, total sugar, reducing sugar and non reducing sugar content were more in diseased leaves compared to healthy leaves. Further, resistant and moderately resistant varieties recorded more sugars than susceptible ones.

Total sugar content was more in diseased leaves compared to healthy leaves. Maximum sugar content of 16.43 mg/dry wt. was recorded in diseased leaves of GPBD-4 against 14.40 mg/dry wt. in healthy leaves (Table 30). While, the least total sugar content of 11.29 mg/dry wt. was recorded in healthy leaves of KRG-1 compared to 14.21 mg/dry wt. in diseased leaves.

Reducing sugar content in healthy and diseased leaves followed the same trend of results as observed in total sugars. Varieties *viz.*, Dh-22 (Red) and GPBD-4 recorded highest sugar content of 13.99 mg/dry wt. and 13.76 mg/dry wt., respectively in diseased leaves. Corresponding healthy leaves of same variety showed lesser reducing sugar content in Dh-22 (Red) and GPBD-4 (11.32 and 11.42 mg/ dry wt., respectively). The least reducing sugar content in diseased leaves was present in KRG-1 (11.52 mg/dry wt.), while healthy leaves of same variety showed lesser content (9.09 mg/ dry wt.) (Table 30).

Table 30: Biochemical parameters of healthy and diseased leaves of resistant, moderately resistant and susceptible varieties as influenced by rust of groundnut caused by *P. arachidis*.

Sl. No.	Genotype	Total sugar (mg/dry wt).		Reducing sugar (mg/dry wt).		Non-reducing sugar (mg/dry wt).		Phenol (mg/dry wt).		Orthodihydroxy phenol (mg/dry wt).		Protein (mg/dry wt).	
		H	D	H	D	H	D	H	D	H	D	H	D
1	Dh-22 (Red)	13.71	16.25	11.32	13.76	2.39	2.49	1.46	0.65	0.98	0.91	6.47	4.79
2	GPBD-4	14.4	16.43	11.42	13.99	2.88	3.08	1.61	0.66	1.00	0.83	6.68	4.61
3	K-134	12.94	15.56	10.82	12.44	2.12	2.10	1.24	0.61	0.94	0.84	4.36	4.10
4	KRG-1	11.29	14.21	9.09	11.52	1.80	1.89	0.67	0.49	0.76	0.56	3.21	3.54
5	R-8088	12.40	15.64	10.39	12.48	2.01	2.01	1.07	0.60	0.95	0.86	4.81	3.80
6	TMV-2	12.43	13.28	9.69	11.62	1.60	1.66	0.80	0.55	0.73	0.61	3.92	3.90

Note : H- Healthy leaves
D- Diseased leaves

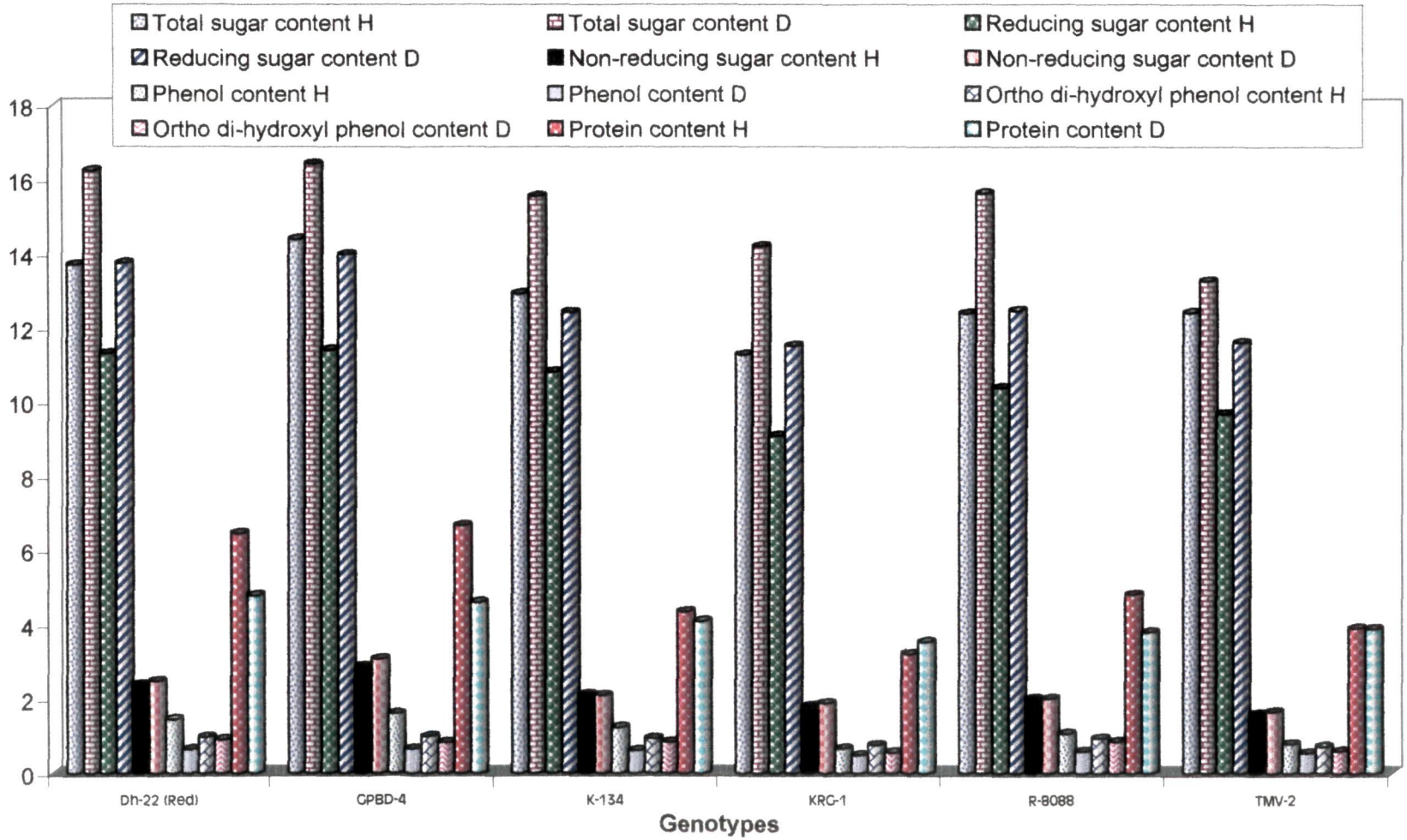


Fig. 17. Biochemical parameters in healthy and diseased leaves of resistant, moderately resistant and susceptible varieties as influenced by rust of groundnut.

Non-reducing sugar content in healthy and diseased varied among varieties. The content ranged from 1.60 to 2.88 mg dry wt. in healthy leaves, while it was 1.66 to 3.08 mg/dry wt in diseased leaves in different varieties. The highest non-reducing sugar content of 3.08 and 2.49 mg/dry wt. was noticed in the diseased leaves of GPBD-4 and Dh-22 (Red), respectively. While, same variety showed less content (2.88 and 2.39 mg/dry wt., respectively) in healthy leaves. Moderately resistant varieties recorded slightly lesser non reducing sugar content compared to resistant varieties but similar trend of results were observed with respect to non-reducing sugar content in diseased versus healthy leaves as observed in reducing sugar content (Table 30).

In all, diseased leaves of all varieties showed more total, reducing and non-reducing sugar content as compared to healthy leaves. Further, both resistant and moderately resistant varieties recorded more sugars than susceptible ones.

Total phenol and orthodihydroxy phenol

More content of phenolics was recorded in healthy leaves than in diseased ones. The resistant varieties *viz.*, GPBD-4 and Dh-22 (Red) recorded highest phenol content of 1.61 and 1.46 mg/dry wt respectively. While corresponding diseased leaves of same varieties contained less phenol content (0.66 and 0.65 mg/dry wt.). The healthy leaves of susceptible variety KRG-1 showed least phenol content (0.67 mg/dry wt.), while it was 0.49 mg/dry wt. in diseased leaves (Table 30).

similarly, healthy leaves showed more orthodihydroxy phenol content when compared to diseased leaves. The highest content was observed in

GPBD-4 (1.00 mg/dry wt) followed by Dh-22 (Red) (0.98 mg/dry wt). The diseased leaves of same varieties recorded lesser content of 0.83 and 0.91 mg/dry wt., respectively. The least orthodihydroxy phenol content of 0.73 mg/dry wt. was recorded in healthy leaves of TMV-2, while in diseased leaves it was 0.61 mg/dry wt.

Protein

The highest protein content of 6.68 mg/dry wt. was recorded in the healthy leaves of GPBD-4 followed by 6.47 mg/dry wt. in Dh-22 (Red) and R-8808 (4.81 mg/dry wt.). However, the diseased leaves of corresponding varieties recorded lesser content of protein (Table 30) .

Thus, the results revealed that, phenol, orthodihydroxy phenol and protein contents were more in healthy leaves as compared to diseased leaves. Further, resistant and moderately resistant varieties showed more contents of these biochemicals than susceptible ones.

STUDIES ON VARIABILITY IN *P. arachidis*

The studies on variability in *P. arachidis* has a greater significance in breeding genotypes for resistance against rust. Hence, attempts were made in the present investigation to study the variation in morphological characters of different isolates and their differential reaction on selected host differentials.

Variation in morphological characters of different isolates of *P. arachidis*

The morphological characters such as colour, shape and size of both pustules and uredospores of 23 isolates were recorded on KRG-1 seedlings as explained in "Material and Methods" and the results are presented in Table 31.

Table 31: Morphology of uredial pustule and uredospores of different isolates of *P. arachidis* inoculated on KRG-1 seedlings

Sl No	Name of the isolate	Uredial pustule			Uredospore		
		Colour	Shape	Size (mm)	Colour	Shape	Size (µm)
1	Akola	Brown	Circular	1.24	Brown	Ellipsoid	20.56 X 28.41
2	Aliyarnagar	Brown	Circular	0.86	Brown	Ellipsoid	18.85 X 24.44
3	Annigeri	Brown	Round ellipsoid	1.15	Brown	Ellipsoid	20.21 X 27.82
4	Arabhavi	Brown	Circular	1.10	Brown	Ellipsoid	18.11 X 25.12
6	Bagalkot	Brown	Round ellipsoid	1.20	Brown	Ellipsoid	21.53 X 28.85
8	Bellary	Brown	Circular	1.36	Brown	Ellipsoid	21.52 X 28.25
2	Bheemar-ayanagudi	Brown	Circular	1.18	Brown	Obovoid	16.81 X 26.00
10	Bidar	Brown	Circular	1.11	Brown	Ellipsoid	22.00 X 28.32
5	Bijapur	Brown	Circular	1.35	Brown	Ellipsoid	21.28 X 27.45
11	Coimbatore	Brown	Round ellipsoid	0.98	Brown	Obovoid	20.28 X 28.82
12	Dharwad	Brown	Circular	1.33	Brown	Ellipsoid	21.08 X 28.28
13	Digraj	Brown	Round ellipsoid	1.27	Brown	Ellipsoid	22.00 X 28.08
14	Gangavati	Brown	Circular	0.85	Brown	Obovoid	17.88 X 25.69
16	Gulbarga	Brown	Circular	1.09	Brown	Obovoid	18.26 25.25
17	Jagtial	Brown	Round ellipsoid	1.31	Brown	Ellipsoid	23.00 X 29.78
18	Jalgaon	Brown	Circular	0.96	Brown	Ellipsoid	16.12 X 25.22
15	Junagadh	Brown	Circular	1.41	Brown	Ellipsoid	21.14 X 28.56
19	Khargone	Brown	Round ellipsoid	1.28	Brown	Ellipsoid	21.21 X 30.00
20	Latur	Brown	Circular	1.12	Brown	Obovoid	20.00 X 29.32
7	Mumbai	Brown	Round ellipsoid	1.00	Brown	Obovoid	18.25 X 24.52
22	Raichur	Brown	Circular	1.11	Brown	Ellipsoid	21.21 X 29.50
21	Siruguppa	Brown	Round ellipsoid	1.42	Brown	Ellipsoid	20.62 X 28.58
23	Tirupati	Brown	Circular	1.30	Brown	Ellipsoid	22.00 X 28.56

The results indicated that, there was no variation in colour of pustule produced by all isolates on KRG-1 seedlings. All the 23 isolates produced brown coloured pustules. However, there was little variation in the shape and size of pustules. Out of 23 isolates, 15 isolates produced circular pustules, while in eight isolates round and ellipsoidal pustules were observed. The size of pustule ranged from 0.85 to 1.41 mm in diameter. The highest diameter of 1.41 mm was recorded in Junagadh isolate while, the least diameter (0.85 mm) was in Gangavati isolate.

The uredospores produced by different isolates inoculated on KRG-1 seedlings showed variation in shape and size but not in colour. All the isolates produced brown coloured uredospores. However, little variation was observed with respect to shape and size of uredospores. Out of 23 isolates, 17 produced ellipsoidal uredospores, while obovoid shaped uredospores were observed in six isolates. The six isolates were from Gulbarga, Gangavati, Bheemarayanagudi, Latur, Mumbai and Coimbatore. The size of uredospore ranged between 16.00-23.00 X 24.00-30.00 µm. Based on the morphology of pustule and uredospores, 23 isolates have been grouped into four categories (Table 32).

Pathogenic variability in isolates of *P. arachidis*

An attempt was made in the present study to select host differential to find out the variation existing in *P. arachidis*. While studying the genotypes for resistance against rust during the study from germplasm pool, some genotypes showed differences in their resistance *viz.*, resistant, moderately resistant and susceptible indicating different degree of resistance and

Table 32: Grouping of isolates of *P. arachidis* based on morphological characters of pustule and uredospore.

Group	Isolate chararecters	Isolates
I	Brown coloured, circular shaped pustules measuring 0.85-1.10 mm in diameter. Uredospores brown, ellipsoid in shape and measuring 16-19 X 24-26 µm in size.	Aliyarnagar Arabhavi Jalgaon (3)
II	Brown coloured, circular shaped pustules measuring 0.85-1.10 mm in diameter. Uredospores brown, obovoid in shape and measuring 16-19 X 24-26 µm in size.	Coimbatore Gangavati Gulbarga Mumbai (4)
III	Brown coloured, round ellipsoid shaped pustules measuring 1.11-1.42 mm in diameter. Uredospores brown, ellipsoid in shape and measuring 20-23 X 28-29 µm in size.	Akola, Annigeri, Bagalkot, Bellary, Bijapur, Dharwad, Digraj, Jagtial Junagadh, Khargone Raichur, Siruguppa Tirupati, (14)
IV	Brown coloured, round ellipsoid shaped pustules measuring 1.11-1.42 mm in diameter. Uredospores brown, obovoid in shape and measuring 20-23 X 28-29 µm in size.	Bheemarayanagudi, Latur (2)

susceptibility to the rust cultures. On the basis of disease reaction, initially 40 genotypes from germplasm were selected. After repeated and vigorous screening against the Raichur rust culture, only seven genotypes (Dh-22(Tan), Dh-22 (Red), Dh-53, ICGV-91116, R-9227, R-2001-1 and JL-24) were selected which showed consistent reaction to the rust culture and others were deleted from the set. A set of seven genotypes was composed and fixed as proposed set of differential hosts for studying variability of *P. arachidis*.

Further, the studies revealed that, all the isolates inoculated on proposed host differentials did not behave differentially in producing the disease reaction. However, little variation was observed with few isolates. Out of 23 isolates inoculated, 11 isolates produced "+" types by affecting all the differentials tested and such isolates are *viz.*, Raichur, Gulbarga, Bellary, Gangavati, Dharwad, Siruguppa, Bidar, Bheemarayanagudi, Bagalkot, Jagtial and Tirupathi (Table 33). However, 12 isolates produced both "+" and "–" types. Among them, Khargone isolate was least virulent by infecting only four differentials *viz.*, Dh-22 (Tan), Dh-53, ICGV-91116 and JL-24. While, Aliyarnagar and Coimbatore isolates infected five differentials but did not produce "+" type infection on Dh-22 (Red) and R-9227. All the isolates produced "+" type infection on highly susceptible national check variety, JL-24.

MECHANISMS OF SLOW RUSTING IN GROUNDNUT GENOTYPES

Twenty one genotypes of groundnut were screened against *P. arachidis* to identify the slow rusters. The reaction of different genotypes for various

Table 33: Infection types produced by different rust isolates of *P. arachidis* on the proposed differentials

Sl. No.	Name of the isolate	Reaction of differentials						
		Dh-22(T)	Dh-22(R)	Dh-53	ICGV-91116	R-9227	R-9248	JL-24
1	Akola	+	+	+	+	-	+	+
2	Aliyarnagar	+	-	+	+	-	+	+
3	Annigeri	+	-	+	+	+	+	+
4	Arabhavi	+	+	+	+	-	+	+
5	Bagalkot	+	+	+	+	+	+	+
6	Bellary	+	+	+	+	+	+	+
7	Bidar	+	+	+	+	+	+	+
8	Bheemaraya nagudi	+	+	+	+	+	+	+
9	Bijapur	+	+	+	+	-	+	+
10	Coimbatore	+	-	+	+	+	+	+
11	Dharwad	+	+	+	+	+	+	+
12	Digraj	+	+	+	+	-	+	+
13	Gangavati	+	+	+	+	+	+	+
14	Gulbarga	+	+	+	+	+	+	+
15	Jalgaon	+	+	+	+	-	+	+
16	Jagtial	+	+	+	+	+	+	+
17	Junagadh	-	+	+	+	-	+	+
18	Khargone	+	-	+	+	-	-	+
19	Latur	+	+	+	+	-	+	+
20	Mumbai	+	-	+	+	+	+	+
21	Raichur	+	+	+	+	+	+	+
22	Siruguppa	+	+	+	+	+	+	+
23	Tirupati	+	+	+	+	+	+	+

\+ : Infection
\- : No infection

components of slow rusting is presented in Table 34 and 35 (Fig. 18 and Plate 10).

Per cent disease index (PDI)

The significant differences in disease severity was observed among the genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 over rest of the genotypes at 54, 61, 68, 75 and 82 DAS (Table 34).

Rate of infection ("r")

The data on rate of infection revealed that, the lowest average 'r' was observed in Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 which ranged between 0.015 to 0.028, where as in other genotypes the value of 'r' ranged between 0.038 to 0.046 (Table 35).

Area Under Disease Progress Curve (AUDPC)

Area Under Disease Progress Curve was minimum in the genotypes Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 where in the values ranged between 574.63 to 983.22. On the other hand, AUDPC values ranged from 1071.63 in R-9251 to the highest AUDPC of 1748.88 in M-II (Table 35).

Latent Period (LP)

The average number of days taken for appearance of first rust pustule from the day of inoculation ranged from 6.2 days in M-I to 16.27 days in GPBD-4. The latent period of rust in groundnut genotypes varied significantly between slow rusters (Plate 10) and fast rusters. The genotypes

Table 34: Per cent disease index of groundnut rust caused by *P. arachidis* on different genotypes of groundnut at weekly interval

Sl. No.	Genotype	Per cent disease index (PDI)					
		47 DAS	54 DAS	61 DAS	68 DAS	75 DAS	82 DAS
1.	Dh-22(Red)	13.44 (21.47)	15.93 (23.53)	19.63 (26.30)	23.00 (28.64)	25.13 (30.03)	32.22 (34.57)
2.	Dh-22(Tan)	12.22 (20.44)	13.70 (21.73)	18.15 (25.20)	20.00 (26.57)	24.00 (29.33)	24.11 (29.33)
3.	Dh-3-30	17.41 (22.17)	23.33 (28.89)	33.70 (35.50)	38.89 (38.58)	51.11 (45.74)	74.44 (59.65)
4.	GPBD-4	11.85 (20.14)	14.44 (22.33)	15.01 (22.80)	19.90 (26.49)	23.96 (27.30)	26.11 (30.73)
5.	ICGS-11	16.67 (24.09)	22.96 (28.64)	35.19 (36.39)	43.70 (41.37)	59.63 (50.56)	75.56 (60.51)
6.	ICGS-44	14.44 (22.34)	22.20 (28.11)	22.96 (28.64)	37.04 (37.28)	45.93 (42.68)	55.56 (48.19)
7.	ICGV-93260	13.33 (21.42)	18.15 (25.15)	20.90 (27.20)	22.50 (28.32)	27.22 (32.09)	36.50 (37.17)
8.	ICGV-93261	12.22 (20.45)	14.07 (22.03)	21.23 (27.44)	22.00 (27.97)	26.96 (31.30)	34.04 (35.67)
9.	JL-24	16.30 (23.78)	24.82 (29.86)	39.26 (38.79)	49.63 (44.80)	60.00 (50.78)	82.22 (65.12)
10.	K-134	14.00 (21.97)	18.30 (25.33)	21.50 (27.62)	22.10 (28.04)	28.00 (32.58)	35.36 (36.31)
11.	KRG-1	15.93 (23.50)	22.59 (28.39)	34.07 (35.71)	38.89 (38.57)	55.56 (48.20)	78.89 (62.71)
12.	M-I	20.00 (26.56)	25.18 (30.11)	37.04 (37.50)	50.37 (45.22)	78.15 (62.05)	91.48 (73.13)
13.	M-II	20.37 (26.81)	28.15 (32.02)	35.93 (36.85)	54.82 (47.85)	75.20 (60.13)	91.11 (72.55)
14.	R-8808	15.56 (23.23)	17.48 (24.73)	21.07 (27.27)	25.18 (30.13)	30.09 (33.21)	36.22 (36.99)
15.	R-9214	12.59 (20.76)	18.41 (25.39)	21.30 (227.49)	26.19 (30.79)	30.50 (33.52)	34.07 (35.68)
16.	R-9227	12.96 (21.09)	18.37 (25.40)	20.44 (26.92)	26.20 (30.79)	30.35 (33.43)	34.86 (36.21)
17.	R-9248	12.59 (20.76)	18.87 (25.77)	21.20 (27.42)	26.01 (30.66)	30.60 (33.56)	33.88 (35.61)
18.	R-9251	14.44 (22.33)	22.22 (28.13)	25.92 (30.60)	33.03 (35.06)	44.44 (41.81)	48.52 (44.14)
19.	S-206	17.78 (24.92)	21.48 (27.62)	25.55 (30.35)	36.30 (37.03)	59.26 (50.34)	79.26 (62.50)
20.	TAG-24	16.67 (24.09)	19.63 (26.27)	24.07 (29.38)	37.78 (37.91)	54.07 (47.35)	66.30 (54.28)
21.	TMV-2	19.26 (26.02)	25.18 (29.86)	26.29 (30.84)	36.30 (37.04)	66.67 (54.79)	80.00 (63.38)
	S. Em±	0.92	1.21	1.42	1.45	1.64	1.65
	CD at 1%	NS	3.66	4.30	4.38	4.95	4.98

*Figures in parenthesis indicate angular transformed values

Table 35: Components of slow rusting in different genotypes of groundnut

Sl. No.	Genotypes	Apparent rate of infection	AUDPC value	L. P. (days)	No. of pustules /sq.cm.	Size of pustule (mm^2)	No. of uredospo-res per pustules
1.	Dh-22(Red)	0.1700	785.26	15.33	32.67	0.78	2506.51
2.	Dh-22(Tan)	0.0175	639.70	15.47	33.67	0.63	2632.93
3.	Dh-3-30	0.0418	1090.50	9.13	45.53	1.40	4260.00
4.	GPBD-4	0.0282	574.63	16.27	25.84	0.89	2304.00
5.	ICGS-11	0.0457	1453.17	8.33	65.60	1.49	5234.10
6.	ICGS-44	0.0411	1121.33	8.87	44.40	1.40	3604.93
7.	ICGV-93260	0.0340	958.20	14.20	35.13	0.90	2716.43
8.	ICGV-93261	0.0201	969.57	14.80	35.60	0.98	2800.93
9.	JL-24	0.0400	1560.79	6.60	65.93	1.41	4323.27
10.	K-134	0.0515	938.84	14.53	34.80	1.00	2702.60
11.	KRG-1	0.0498	1389.64	7.47	60.40	1.49	4392.50
12.	M-I	0.0329	1725.36	6.20	70.57	1.41	5487.80
13.	M-II	0.0462	1748.88	6.60	69.53	1.48	5387.77
14.	R-8808	0.0260	982.00	14.87	36.03	0.98	2789.60
15.	R-9214	0.0460	966.67	14.93	35.07	0.93	2780.67
16.	R-9227	0.0645	876.89	14.27	34.60	0.96	2782.10
17.	R-9248	0.0170	983.22	14.30	33.00	0.99	2698.87
18.	R-9251	0.0175	1071.63	11.00	48.87	1.47	3680.33
19.	S-206	0.0418	1337.77	8.00	60.53	1.45	4270.83
20.	TAG-24	0.0282	1239.25	9.33	47.33	1.45	4287.93
21.	TMV-2	0.0457	1428.49	7.67	63.47	1.27	4493.00
	S. Em. ±	--	--	0.57	2.67	0.03	130
	CD at 1%			2.08	10.22	0.14	497

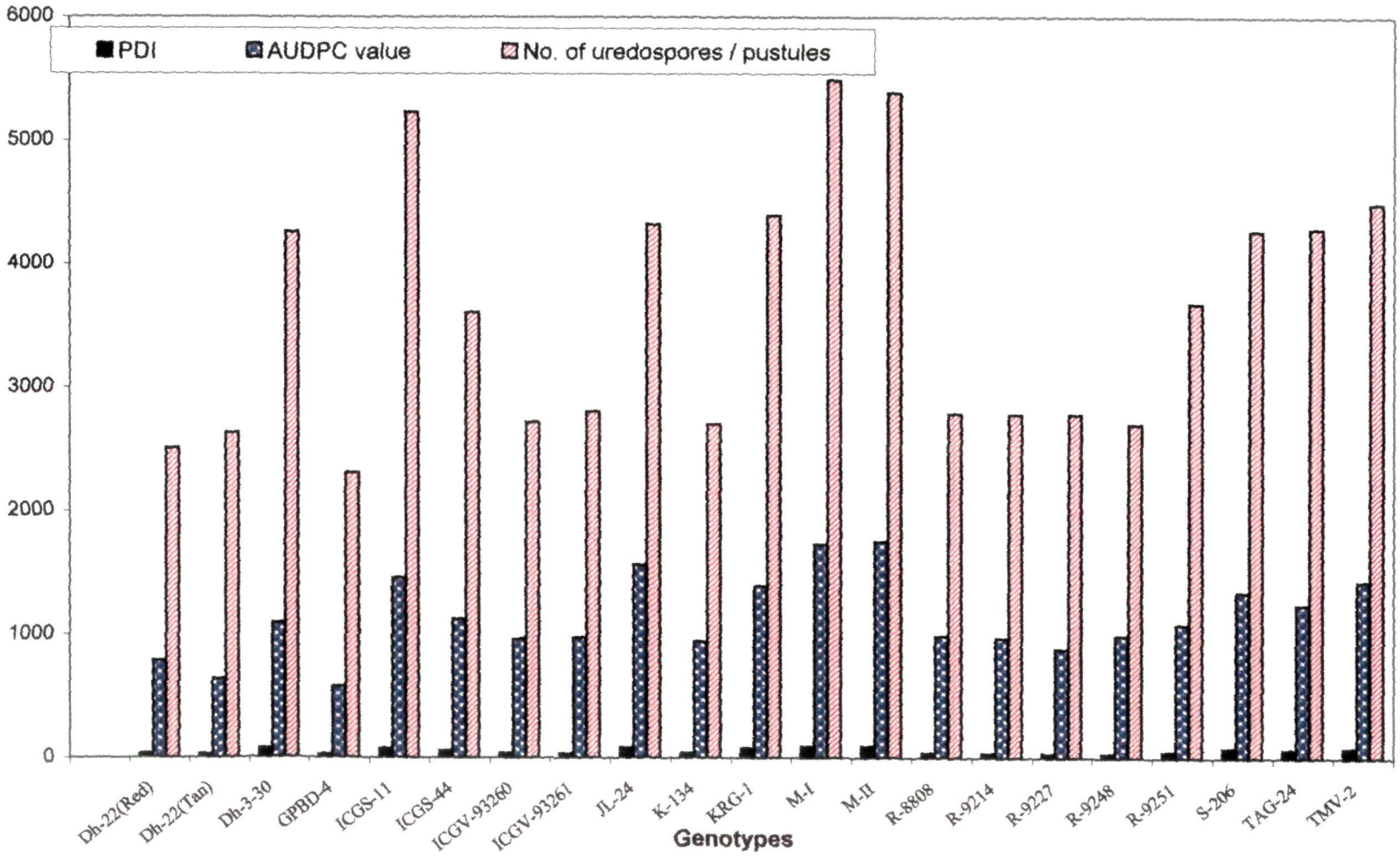
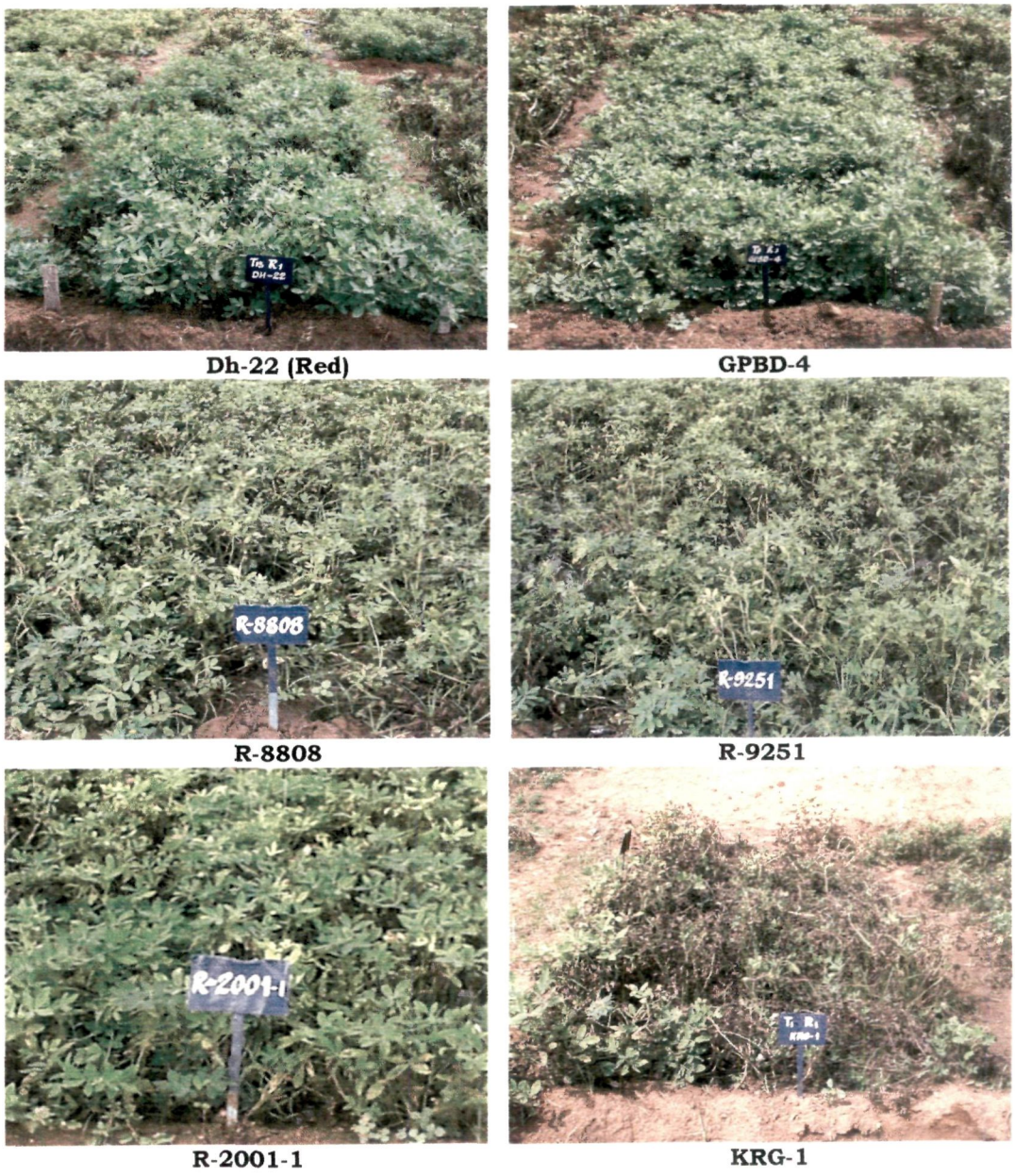


Fig. 18. Components of slow rusting in different genotypes of groundnut.



Dh-22 (Red) GPBD-4

R-8808 R-9251

R-2001-1 KRG-1

Plate 10. Slow rusters of groundnut in comparison with highly susceptible variety, KRG-1.

viz., Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 have shown longer latent period of 14.20 to 16.27 days as against fast rusters, where in it ranged between 6.20 to 11.00 days (Table 35).

Number of pustules/sq. cm.

The number of pustules/sq. cm ranged from 25.84 in GPBD-4 to 70.57 in TMV-2. The significant difference was observed among the genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 over other genotypes (Table 35).

Size of pustule (mm^2)

The size of pustule in each genotype ranged between 0.89 mm^2 in GPBD-4 to 1.49 mm^2 in KRG-1. The genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 have shown smaller sized pustules of 0.89 to 1.00 mm^2 (Table 35).

Number of uredospores/pustule

It ranged from 2304.00 in GPBD-4 to 5487.80 in M-I. The genotypes, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 have shown considerably less number of uredospores/pustules *vis-a-vis* other genotypes (Table 35).

COST EFFECTIVE INTEGRATED DISEASE MANAGEMENT

The experiment on cost effective integrated disease management of groundnut rust using fungicides and botanical (Neem seed kernel extract)

was conducted during *kharif,* 2002 and 2003. The results are presented in Table 36 & 37 and Fig. 19 (Plate 11 and 12).

Per cent disease index (PDI)

The results obtained during 2002 revealed that all the treatment combinations were significantly superior to untreated control at each date of observation (Table 36).

During first observation (55 DAS), the treatments *viz.,* H-H-H, P-P-P, D-D-D and H-N-H were found on par with each other with PDI of 20.96, 22.11, 20.00 and 21.85 PDI, respectively and they were significantly superior to all other treatments except P-N-P (24.07), D-N-D (24.17) and N-P-N (23.70). Similarly, the treatments *viz.*, C-C-C, C-N-C, N-N-N, P-N-P, N-P-N, N-H-N, N-C-N and N-D-N recorded PDI ranging between 25.55 to 38.86 per cent and were found significantly different from untreated control (43.70%).

On second date of observation (70 DAS), minimum PDI of 25.30 was recorded in plots receiving three consecutive application of hexaconazole (H-H-H) followed by difenconazole (25.85%) and propiconazole (27.74%). On the other hand, NSKE interspersed with chemical fungicides H-N-H, P-N-P and D-N-D recorded PDI between 29.00 to 29.30 and did not differ with each other, but found considerably superior over other treatments receiving other than three consecutive sprays of fungicides and untreated control (61.85%) except C-C-C (33.33%).

At third date of observation (85 DAS), least PDI of 30.37 was obtained in H-H-H which was found to be significantly superior over all other treatment combinations except D-D-D (30.85%). This treatment was followed

Table 36: Integrated disease management of groundnut rust caused by *P. arachidis* during *kharif*, 2002 in groundnut variety KRG-1

Sl. No.	Treatment	Per cent disease index (PDI)				Percent disease control	Yield (q/ha)	% Yield increase over control	Haulm yield (q/ha)	B : C ratio
		I*	II*	III*	Mean					
1.	C – C– C	29.00 (32.58)	33.33 (35.26)	45.93 (42.67)	36.09	42.64	13.52	20.71	21.31	1.57
2.	N – N– N	29.63 (32.96)	45.19 (42.24)	61.48 (51.65)	45.43	27.79	12.01	7.20	16.51	2.13
3.	H – H – H	20.96 (27.23)	25.30 (30.20)	30.37 (33.40)	25.54	59.40	16.73	49.37	25.87	6.13
4.	P – P– P	22.11 (27.98)	27.74 (31.75)	35.12 (36.28)	28.32	54.99	14.86	32.67	23.12	2.04
5.	D – D – D	20.00 (26.55)	25.85 (30.55)	30.85 (33.75)	25.57	59.36	16.21	44.73	25.41	1.52
6.	C– N – C	26.67 (31.15)	45.57 (42.45)	55.93 (48.40)	42.72	32.10	13.01	16.16	19.55	2.53
7.	H – N – H	21.85 (27.87)	29.30 (32.77)	40.26 (39.39)	30.47	51.57	14.01	25.08	23.22	3.34
8.	P – N – P	24.07 (29.38)	29.00 (32.58)	42.22 (40.53)	31.76	49.52	13.34	19.10	22.14	1.68
9.	D – N – D	24.17 (29.44)	29.20 (32.70)	41.80 (40.34)	31.72	49.58	13.21	17.94	22.99	1.32
10.	N – C – N	38.86 (38.55)	55.19 (47.98)	60.55 (51.06)	51.53	18.09	12.09	7.94	18.60	1.25
11.	N – H – N	34.07 (35.72)	44.81 (42.03)	46.57 (43.01)	41.82	34.17	12.52	11.78	19.14	2.72
12.	N – P – N	23.70 (29.12)	34.44 (39.27)	46.67 (43.09)	34.94	44.46	12.99	15.98	18.85	3.21
13.	N – D – N	25.55 (30.35)	34.44 (35.94)	45.93 (42.67)	35.31	57.08	12.56	12.14	19.05	1.73
14	Control	43.70 (41.39)	61.85 (51.87)	83.20 (66.19)	62.92	--	11.20	--	15.20	--
	S.Em±	**0.64**	**0.70**	**0.84**			**0.60**		**0.88**	
	CD at 5%	**1.92**	**2.08**	**2.43**			**1.82**		**2.61**	

*Values in parenthesis are angular transformed values

Cost of the dry pod @ Rs. 1500/Q and haulm @ Rs. 50/Q. Labour charges for three sprays per hectare Rs. 240/-; Quantity of spray solution used per hectare, 1st spray :750 l, 2nd spray : 800 l, 3rd spray :850 l ; Cost of fungicides in Rs./kg or litre Chlorothalonil (500), Hexaconazole (600), Propiconazole (1200), Difenconazole (2200) and Neem seed extract (5).

Table 37: Integrated disease management of groundnut rust caused by *P. arachidis* during *kharif* 2003 in groundnut variety KRG-1.

Sl. No.	Treatment	Percent disease index (PDI)				Percent disease control	Yield (q/ha)	% Yield increase over control	Haulm yield (q/ha)	B : C ratio
		I*	II*	III*	Mean					
1.	C – C– C	32.59 (34.82)	45.93 (42.67)	48.52 (44.15)	42.35	41.95	13.85	32.03	20.37	1.76
2.	N – N– N	33.33 (35.26)	55.93 (48.19)	64.22 (53.25)	51.16	29.90	11.69	11.43	15.75	1.27
3.	H – H – H	22.22 (28.11)	28.85 (32.46)	33.48 (35.43)	28.18	61.37	16.67	58.91	24.97	6.04
4.	P – P– P	22.59 (27.69)	30.33 (33.44)	37.89 (37.94)	30.27	58.51	14.61	39.28	21.56	2.16
5.	D – D – D	24.80 (29.03)	31.20 (33.96)	33.74 (35.49)	29.91	59.00	16.54	57.67	23.45	1.83
6.	C– N – C	35.19 (36.39)	45.19 (42.25)	53.33 (46.92)	44.57	38.91	12.95	23.45	18.65	2.41
7.	H – N – H	25.08 (30.05)	33.19 (35.18)	39.70 (39.06)	32.66	55.24	14.91	42.13	22.63	5.81
8.	P – N – P	31.11 (33.90)	36.85 (37.43)	40.44 (39.47)	36.13	50.48	13.49	28.59	21.89	1.78
9.	D – N – D	25.01 (30.00)	32.10 (34.51)	38.86 (38.55)	31.99	56.15	15.24	45.28	22.58	1.92
10.	N – C – N	44.81 (42.03)	54.89 (47.81)	63.70 (52.74)	59.30	18.72	12.14	15.72	17.68	2.32
11.	N – H – N	38.59 (38.41)	47.81 (43.74)	44.70 (41.96)	46.26	36.59	12.25	16.77	19.28	3.44
12.	N – P – N	29.30 (32.77)	35.18 (36.37)	52.67 (46.52)	43.93	39.78	12.07	15.06	18.09	1.98
13.	N– D – N	29.07 (32.62)	38.48 (38.35)	51.57 (45.91)	45.03	38.28	12.37	17.92	19.16	2.71
14	Control	51.48 (45.86)	77.04 (61.17)	90.37 (71.30)	72.96	--	10.49	--	11.39	
	S.Em±	1.10	0.72	0.87			0.52		0.86	
	CD at 5%	3.83	2.04	2.54			1.47		2.50	

*Values in parenthesis are angular transformed values

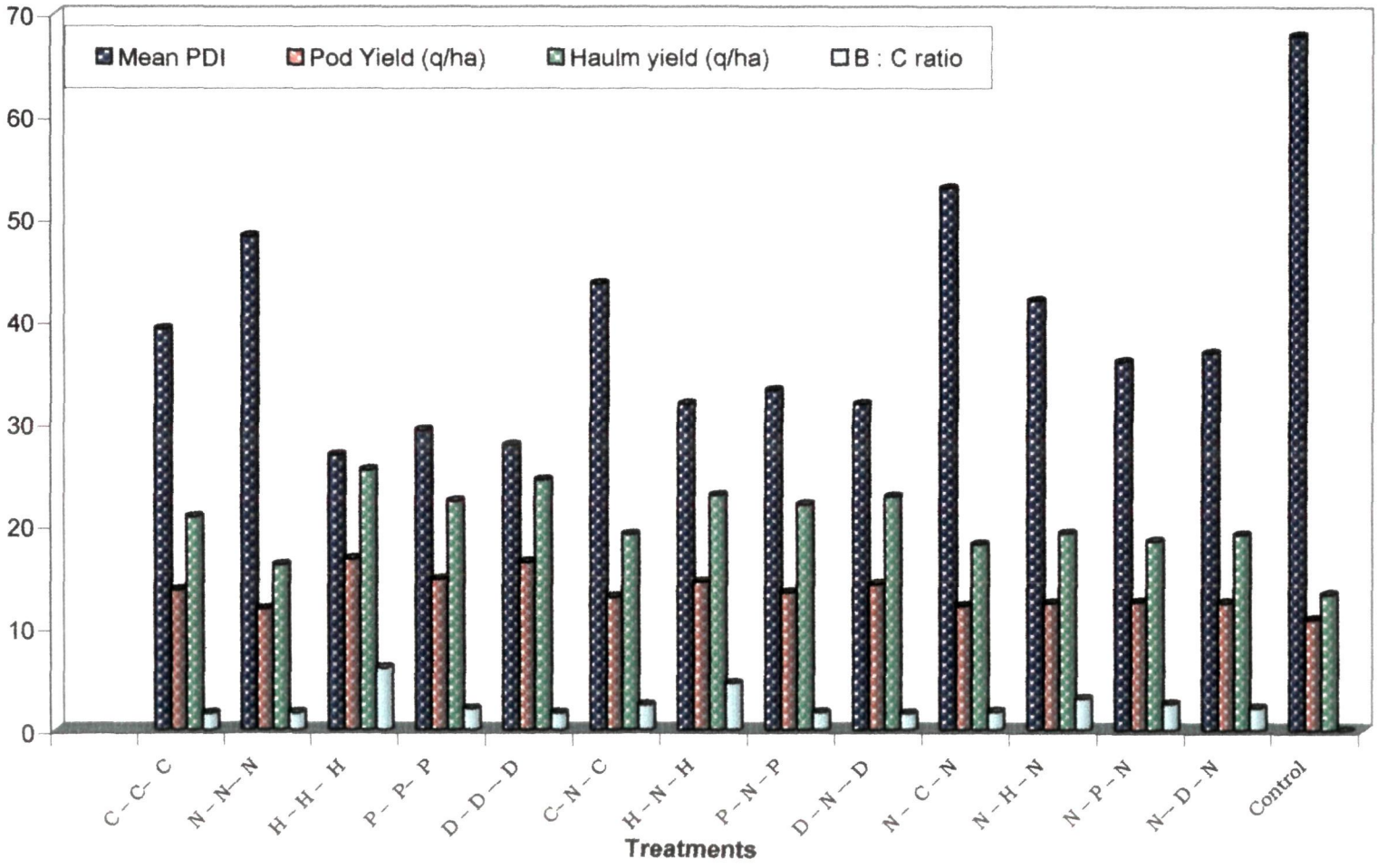


Fig. 19. Effect of different treatment combinations on mean PDI of rust, pod yield, haulm yield and BCR in groundnut.

Plate 11. Effect of different treatment combinations on incidence of groundnut rust for effective cost integrated management.

H – H – H Control

H – N – H Control

Plate 12. Best cost effective treatments v/s control in the integrated management of rust of groundnut (*P. arachidis*).

by P-P-P which recorded 35.12 per cent disease index, while H-N-H, D-N-D and P-N-P recorded 40.26, 41.80 and 42.22 per cent, respectively and were on par with each other. They were considerably more effective than rest of the treatments. The PDI of treatments C-C-C, C-N-C, N-N-N, N-P-N, N-H-N, N-C-N and N-D-N ranged between 45.93 to 61.48, however they were superior to untreated Control (83.20%).

Thus from the mean PDI, it is evident that, three consecutive application of hexaconazole and difenconazole recorded least PDI of 25.54 and 25.57, respectively. Treatment which received three consecutive application of propiconazole (P-P-P) was next best treatment which recorded mean PDI of 28.32. Combination of hexaconazole alternated with NSKE (H-N-H) showed mean PDI of 30.47 followed by combination of D-N-D (31.72%) and P-N-P (31.76%) which did not differ each other but were considerably more effective than rest of the treatments.

The highest per cent disease reduction of 59.40 was recorded in H-H-H followed by D-D-D (59.36%) and P-P-P (54.99%). While treatments H-N-H, D-N-D and P-N-P recorded considerably more per cent disease reduction (51.57, 49.58 and 49.52%, respectively). Least per cent reduction of 18.09 and 27.79 was recorded in N-C-N.

The results obtained during *kharif*, 2003 followed similar trend of results as observed during *kharif*, 2002. All the treatments were significantly superior to untreated control at every observation (Table 37). At first date of observation, the treatments *viz.*, H-H-H, D-D-D, P-P-P, H-N-H and D-N-D did not differ significantly with each other where in the PDI ranged between 22.22

to 25.08, but were significantly more effective than rest of the treatments and untreated control (51.48%). On second date of observation, H-H-H (28.85%) was found highly effective followed by P-P-P (30.33%) and D-D-D (31.20%). On the other hand, NSKE interspersed treatments H-N-H and D-N-D were also effective by recording PDI of 33.19 and 32.10, respectively and also on par with H-H-H, P-P-P and D-D-D but significantly different from other treatments. There was significant difference in per cent disease index of treatment combinations on third date of observation also. The treatments *viz.*, H-H-H and D-D-D recorded least PDI of 33.48 and 33.74, respectively which were considerably superior over all other treatment combinations except P-P-P (37.89%).

Further, the mean PDI was lowest in H-H-H (28.18) followed by D-D-D (29.91) and P-P-P (30.27). The treatment combination of fungicides with botanical *viz.*, D-N-D and H-N-H recorded mean PDI of 31.99 and 32.66, respectively when compared to highest mean PDI of 72.96 per cent in control plot (Table 37). The per cent reduction of disease was highest in H-H-H (61.37%) followed by D-D-D (59.00%) and P-P-P (58.51%). Whereas, per cent disease reduction was 55.24, 56.15, and 50.48 in H-N-H, D-N-D and P-N-P, respectively. The least disease reduction was recorded in N-C-N (18.72%) and N-N-N (29.90%).

The mean data (Table 38) of two years indicated that, the treatment H-H-H recorded least PDI (26.87) followed by D-D-D (27.84) and P-P-P (29.30), while H-N-H recorded the mean PDI of 31.90. The disease reduction of 60.39,

Table 38: Effect of different treatment combinations on pod and haulm yield and benefit cost ratio (BCR) in the integrated disease management of groundnut rust caused by *P. arachidis* during *kharif* 2002-03 in groundnut variety KRG-1

Treatment	Per cent Disease Index (PDI)			Per cent reduction over control	Pod yield (q/ha)			Per cent increase over control	Haulm yield (q/ha)			Per cent increase over control	BCR		
	K-02	K-03	Mean		K-02	K-03	Mean		K-02	K-03	Mean	56.69	K-02	K-03	Mean
C – C– C	36.09	42.35	39.22	42.30	13.52	13.85	23.69	26.37	21.31	20.37	20.84	21.42	1.57	1.76	1.67
N – N-- N	45.43	51.16	48.30	28.85	12.01	11.69	11.85	9.32	16.51	15.75	16.13	21.27	2.13	1.27	1.70
H – H – H	25.54	28.18	26.87	60.39	16.73	16.67	16.70	54.14	25.87	24.97	25.42	91.12	6.13	6.04	6.09
P – P– P	28.32	30.27	29.30	56.75	14.86	14.61	14.74	35.98	23.12	21.56	22.34	67.96	2.04	2.16	2.10
D – D --D	25.57	29.91	27.84	59.18	16.21	16.54	16.38	51.20	15.41	23.45	24.43	83.68	1.52	1.83	1.68
C– N – C	42.72	44.57	43.65	35.51	13.01	12.95	12.98	19.81	19.55	18.65	19.10	43.60	2.53	2.41	2.47
H – N – H	30.47	32.66	31.90	53.41	14.01	14.91	14.46	33.61	23.22	22.63	22.93	72.40	3.34	5.81	4.58
P – N – P	34.76	36.13	33.22	50.00	13.34	13.49	13.42	23.85	22.14	21.89	22.02	65.56	1.68	1.78	1.73
D – N --D	31.72	31.99	31.87	52.87	13.21	15.24	14.23	31.61	22.99	22.58	22.79	71.35	1.32	1.92	1.62
N – C – N	51.53	59.30	53.00	21.98	12.09	12.14	12.12	11.83	18.60	17.68	18.14	36.39	1.25	2.32	1.79
N – H – N	41.82	46.26	42.00	35.38	12.52	12.25	12.39	14.28	19.14	19.28	19.21	44.43	2.72	3.14	2.93
N – P – N	34.94	43.93	36.06	42.12	12.99	12.07	12.53	15.52	18.85	18.09	18.47	38.87	3.21	1.98	2.60
N – D – N	35.31	45.03	36.92	47.68	12.56	12.37	12.47	15.03	19.05	19.16	19.11	43.68	1.73	2.71	2.22
Control	62.92	72.96	67.94	--		10.49	10.85	--	15.20	11.39	13.30	--	--	--	--

59.18, 56.75 and 53.41 per cent was observed in H-H-H, D-D-D, P-P-P and H-N-H, respectively.

Pod yield

The pod yield of groundnut was significantly superior in all the treatments compared to control during both years (Table 36 & 37). Further, pod yield differed significantly among the treatments during both the years where in, the untreated control recorded minimum yield, while the plots which received three sprays of hexaconazole and difenconazole produced maximum yield during *kharif*, 2002 (16.73 and 16.21 q/ha) and *kharif*, 2003 (16.67 and 16.54 q/ha), respectively and were found on par with each other. The mean data on yield and per cent increase in yield (Table 38) was highest in H-H-H (16.70 q/ha & 54.14%) followed by D-D-D(16.38 q/ha & 51.20%) and P-P-P (14.74 q/ha & 35.98%). The treatment H-N-H recorded the mean pod yield of 14.46 q/ha with 33.61 per cent increase in pod yield over control.

Haulm yield

The haulm yield of groundnut also differed significantly among the treatments with different treatment combinations during both years. Maximum haulm yields were recorded in H-H-H (25.87 q/ha) and D-D-D (25.41 q/ha) and were significantly different from other treatment combinations except H-N-H (23.22 q/ha) during 2002. Where as during 2003, H-H-H (24.97 q/ha), D-D-D (23.45 q/ha), H-N-H (22.63 q/ha) and D-N-D (22.58 q/ha) produced significantly more haulm yield than rest of the treatments and were found on par with each other. The mean data (Table 38) of two years indicated that, the treatment H-H-H recorded the highest haulm

yield (25.42 q/ha) followed by D-D-D (24.43 q/ha) and H-N-H (22.93 q/ha), with per cent increase over control of 91.12, 83.68 and 72.40, per cent respectively.

Benefit cost ratio (BCR)

The results revealed that, highest benefit was obtained in H-H-H (6.13) followed by H-N-H (3.34) and N-P-N (3.21) and lowest in N-C-N (1.25) and D-D-D (1.52) during 2002 (Table 36). During 2003 also, maximum benefit was recorded in H-N-H (6.04) and H-N-H (5.81) and lowest in N-N-N (1.27) and D-D-D (1.83) (Table 37). From the mean data of two years, it is evident that, benefit cost ratio of 6.09 was recorded in H-H-H followed by 4.58 in H-N-H (Table 38).

DISCUSSION

V DISCUSSION

The groundnut rust caused by *P. arachidis* Speg. is one of the most important foliar diseases and causes yield losses from 10 to 50 per cent depending on the severity. It appeared in severe form in Raichur district (Benagi, 1991) and hence Raichur has been considered as 'hot spot' for outbreak of rust. Now, the disease has become one of the major constraints for groundnut cultivation, particularly in northern Karnataka. Pande and Narayan Rao (2000) recorded highest severity of 81-90 per cent and more recently, 11-80 and 41-80 per cent of disease has been reported in Koppal and Raichur districts, respectively (Anon., 2002). Hence, an attempt was made to know in detail the various aspects of the disease.

SURVEY AND SURVEILLANCE FOR DISEASE

In the present study, an intensive fixed plot survey for rust of groundnut was carried out during *Kharif* 2002 and 2003 in major groundnut growing areas of northern Karnataka to get precise information on the distribution and intensity of the disease. The data on survey revealed that, the rust incidence varied from locality to locality, because of type of variety grown, environmental conditions, cropping pattern and build up of inoculum. It was observed that, disease severity was more in irrigated crop than in rainfed. This may be attributed to more humidity and cooler temperatures in the crop canopy which confirms the findings of Krishna Prasad *et al.* (1979).

The average disease severity varied in various locations in different districts owing to varied agroclimatic conditions and also different cultivars

used. In Northern Karnataka, the average disease severity was found more in Raichur district (65.50%) followed by Gulbarga (60.26%) and Koppal (59.53%) and least in Dharwad with 37.31 per cent. Such variation in rust severity and wide spread nature have been reported by earlier workers (Subrahmanyam *et al.*, 1979; Ghewande and Mishra, 1983 and Siddaramaiah *et al.*, 1979a).

Maximum disease severity of 73.40 per cent was recorded in Arakera followed by Chandrabanda (72.09%) and Jangamarahalli village (70.75%) of Raichur district, where in conditions for development and spread of disease were prevailing during *Kharif* season. These observations are in agreement with the earlier reports by Benagi (1991) and Pande and Narayan Rao (2000) in groundnut rust and Hegde (2001) in case of soybean rust.

Further, the maximum disease severity of rust in Raichur, Koppal and Gulbarga districts may be attributed to extensive and continuous cropping of groundnut. The results are in agreement with the findings of Subrahmanyam *et al.*(1979) and Subrahmanyam and Mc Donald (1983). Hence, Raichur district was considered as 'hot spot' for groundnut rust (Benagi, 1991).

Lower disease severity (23.99%) recorded in Halaharti village of Gulbarga district followed by Narendra (33.54%) and Manakod village (36.12%) of Dharwad district may be attributed to cultivation of resistant/tolerant varieties and groundnut as sole crop under rainfed conditions and early sowing (May last week to June first week). Similar conditions were prevailing in Haveri and Belgaum districts also.

Earlier reports (Benagi, 1991) of survey in groundnut rust recorded maximum disease incidence of 35.00 per cent during 1991 in Raichur district

which was lower than that of 65.50 per cent recorded as average of 2002 and 2003 during present study. Similarly, in Dharwad district the maximum disease severity of 10.00 per cent was recorded during 1991 which was also lower than 37.31 per cent recorded as average of 2002 and 2003. Thus, the increasing tendency in disease severity of groundnut rust can be attributed to late sowing (Late June to July) due to irregularity in supply of water from command area canals and unpredictable start of rainy season and negligence in application of suitable fungicides and also the cultivation of highly susceptible varieties of groundnut.

LOSS ASSSESSMENT

Number of hexaconazole sprays required to manage the disease

Per cent disease index

The disease appeared on both the varieties of groundnut *viz.*, KRG-1 and K-134 on 31st standard week during both *kharif* 2002 and 2003. However, the intensity of disease was much lower on K-134 when compared to KRG-1 during both the years.

Fungicidal sprays were imposed irrespective of the disease incidence at 40 DAS and subsequent sprays were given at weekly interval in respective treatments. Per cent disease index on crop receiving one and two sprays did not differ upto 54 days on KRG-1 and up to 61 days in K-134.

In KRG-1, crop receiving fungicidal spray at 40th day and 47th day against the rust disease recorded significantly higher disease index than the plots receiving three and more sprays where in no remarkable difference was

noticed at different intervals of observation. On the other hand, in K-134 also, plots sprayed three to six times did not differ in between but recorded significantly less PDI than in crop sprayed only once. However in plots sprayed twice, the disease advancement was slowed down after 61 days to record PDI which was on par with three and also more number of sprays.

The reduction in disease on KRG-1 was about 63.90 to 65.79 per cent during *kharif* 2002 and 63.23 to 66.17 per cent during *kharif* 2003 on crop sprayed three to six times, while it was less in crop receiving one and two sprays. Similarly, in K-134, per cent disease reduction was comparatively less in plots sprayed once than in plots receiving two to six fungicidal applications. Effectiveness of fungicidal sprays to lower the disease advancement is on record (Benagi, 1995; Patil, 1996 and Hegde, 2001).

The results of the experiments from both the years clearly indicated that, three fungicidal sprays on KRG-1 (Susceptible) and two on K-134 (moderately resistant) are sufficient to lower the disease index. Similar views were put forth by Hundekar (1999) and Hegde (2001) in control of soybean rust.

Pod yield

Spraying the fungicide significantly improved the pod yield of KRG-1 than untreated control. Maximum yields were obtained from the plots sprayed three or more times which is attributed to the lower disease index in these treatments.

In moderately resistant genotype K-134, significant higher yields are recorded from plots receiving two or more sprays than the plots sprayed once and untreated control. These findings are in agreement with the reports of Benagi (1995) in late leaf spot of groundnut, Patil (1996) in Sunflower rust, Hundekar (1999) and Hegde (2001) in case of soybean rust studies.

Therefore, the results of two years of field studies proved that, in a susceptible variety KRG-1, three sprays of hexaconazole are sufficient to manage the rust and realise the economic yields, while on moderately resistant variety K-134, two sprays are enough to reduce the disease severity and to obtain higher pod yields.

Haulm yield

Similarly, spraying of fungicides significantly increased the haulm yields of both KRG-1 and K-134. In KRG-1, maximum haulm yield were obtained in plots receiving two to six sprays which is mainly due to lower disease index in these treatments. Increase in haulm yields are recorded from plots receiving two to six sprays than plots receiving one spray. Similarly, in moderately resistant variety K-134 significantly higher haulm yields were recorded from plots receiving two or more sprays than the plots sprayed once and untreated control. These findings are in line with the reports of similar views expressed by Subrahmanyam *et al.*(1984) in groundnut rust, Benagi (1995) in late leaf spot of groundnut, Patil (1996) in sunflower rust and Hundekar (1999) and Hegde (2001) in soybean rust. Therefore, studies indicated that, giving two or more sprays could help to enhance the yield levels in groundnut by way of controlling the disease.

Benefit cost ratio

Higher benefits were recorded from treatments with two and three hexaconazole (0.1%) sprays against rust disease in groundnut variety KRG-1 during both the years. Similar findings in getting maximum benefits were obtained by Hundekar (1999) in JS-335 and PK-1029 varieties, when sprayed with three sprays of hexaconazole in soybean rust. Though the benefits were same in both the treatments farmers have to loose 1.92 q/ha and 2.29 q/ha of pod and haulm yield, respectively if they spray the crop twice when compared to three fungicidal applications to the crop. Though two fungicidal applications seem to be sufficient to overcome the disease out break, but it can not be practical to sacrifice 1.92 q/ha and 2.29 q/ha of pod and haulm yield, respectively to obtain higher benefits.

Similarly, in case of moderately resistant groundnut cultivar K-134 every unit investment has resulted in higher benefit from treatments receiving two and three sprays than rest of the treatments. However, plots sprayed twice recorded 1.46 q/ha and 2.46 q/ha pod and haulm yield, respectively than crop sprayed twice. Here too the higher benefits in treatment with only one spray is because of less requirement of plant protection chemical.

It may be inferred that, the number of sprays required *viz.*, three and two for KRG-1 and K-134, respectively to obtain maximum yield is essential. When disease pressure is moderate to less, two sprays and one spray of hexaconazole (0.1%) is enough to realise maximum benefit in KRG-1 and K-134, respectively. Whereas, when disease pressure is very high, three and

two sprays of hexaconazole are necessary to realise maximum benefits in KRG-1 and K-134, respectively.

Crop loss model

Importance of disease is adjudged based on the loss in yield caused by the disease. Several workers have indicated the loss in pod yield (Benagi, 1995; Patil, 1996 and Hegde, 2001).

Prediction of loss due to disease are prerequisite for application of management practices, for which yield loss models are essential. Accurate information, concerning loss is needed by groundnut growers and plant protection specialists to develop decision thresholds for determining, when cost effective management measures should be deployed (Nutter, 1993). In the present study, yield loss models were developed by using PDI as input variable to predict loss in KRG-1 and K-134 due to rust. The crop loss models developed (Fitted) depicts the maximum correlation with given PDI and expected yield. Model developed only helps to calculate the yield with given PDI. As fitting of the model is dependent on maximum R^2 it can be fit anywhere from PDI taken at 47 to 82 DAS.

The coefficient of determination (R^2) value indicates the validation of the model developed. The lesser R values in the pod yield models indicates that model could account only for lesser validation. This shows that the models need to be improved taking into consideration environmental and physiological factors as well as stages of growth of the plants. However, in other models the predicted yield loss values in both the varieties were nearer to the observed values and indicated that the models developed were correct.

Hence, the linear regression model developed by using variable PDI is appropriate for prediction of yield loss due to groundnut rust.

EPIDEMIOLOGICAL STUDIES

Viability and perpetuation of uredospores of *P. arachidis* under different storage conditions

As a part of epidemiological study, the perpetuation of pathogen in host debris was studied. The production of teliospores of *P. arachidis* has not been reported so far in South India besides, no reports on alternative hosts. Hence, the possible mode of perpetuation of groundnut rust is by uredospores present on the host. In the present study, germination of uredospores was observed up to 40 days in room (20-25° C) and tree shade (15-20°C), and upto 20 days in glass house (25-28° C) and field (28-30° C). However, no germination was observed after 45 days of storage. The observations indicated that, uredospores are short lived in crop debris. This finding is in accordance with Patel and Vaishnav (1986) who stated that, the viability of uredospores of *P. arachidis* was lost within a short period of 25 days in open condition. Further, germination of uredospores was observed only for 15 days in deep freeze (-5°C) and freeze (4-5°C) conditions, respectively. However, Patil *et al.* (1997) did not get any germination of uredospores for a single day under freeze (4-5°C) and deep freeze (-18°C) conditions. This may be due to the fact that lower temperature (<5°C) causing freezing injury for the germination of uredospores, which needs further study at molecular level.

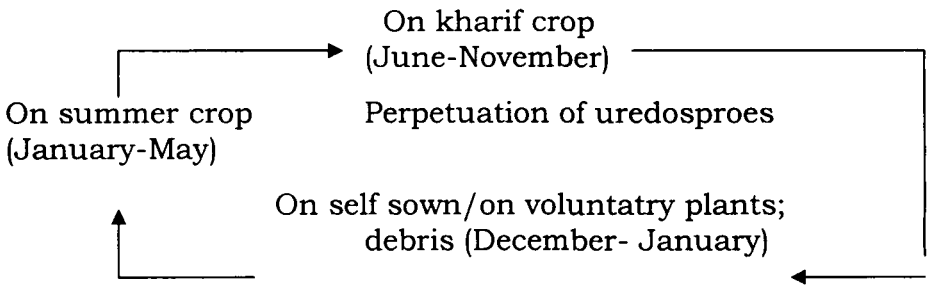
Further, per cent viability of uredospores was decreased with increase in storage period in all the conditions tested. The viability of uredospores was observed up to 40 days of storage in room (20-25 ^{o}C) and tree shade (15-20^{o}C) conditions. This is followed by glasshouse (25-28^{o}C) and field (28-30^{o}C) where in viability of uredospores remained up to 20 days. While there was no germination of uredospores after 45 days of storage. The lowest per cent viable spores of 5.60 and 2.07 was observed in deep freeze (-5 ^{o}C) and freeze (4-5^{o}C) conditions, respectively when stored for 15 days. Similar results were reported by Benagi (1991) incase of rust of groundnut.

Self sown groundnut plants

The survey conducted during off season revealed that, self sown and voluntary groundnut plants found during the month of May and June showed traces of infection of rust. These findings are in agreement with Subrahmanyam and Mc Donald (1982), who reported that, the pathogen survives from season to season on voluntary groundnut plants. Further, the study also revealed that, no infection was found on any of the crop and weed hosts. Similar results were reported by Bromfield and Cavario (1970); and Subrahmanyam and Mc Donald (1982) in case of groundnut rust.

In Northern Karnataka, groundnut is taken up mainly as a *kharif* crop during the months of June-November and as a summer crop during the period of mid January-May. The uredospores occur on *kharif* crop till the end of November. These may go to self sown groundnut plants or they may survive on debris. In the absence of these two also, the spores are capable of

remaining viable for about a month and a half which is true with the present findings and also agrees with findings of Lingaraju *et al.* (1979). At that time, summer crop will be available and the uredospores of pathogen will infect this crop. This summer crop comes to harvest by the end of May. *Kharif* crop starts by June and the spores will infect this crop. In addition to *kharif* and summer season sowings, the crop is cultivated throughout the year in small acreage. This also helps for the survival of pathogen. Hence, the cycle continues. The perpetuation of the uredospores may be represented in the following diagram.



Similarly, Mayee *et al.* (1977) predicted that groundnut rust has a definite pattern of movement in India. In southern states, inoculum is available throughout the year, but to a lesser degree in central India and additional introductions of wind borne spores occur on crops from south. The rust is unlikely to over summer in crop debris under hot climatic conditions in Uttar Pradesh, Bihar, Haryana, Punjab, Rajasthan and northern Madhya Pradesh. Since groundnut is grown in these areas only in

the rainy season, the inoculum possibly is reintroduced annually from south and central India.

Search for telial stage of *P. arachidis*

An effort was made to search for telial stage of *P. arachidis.* The production of teliospore by *P. arachidis* has been reported in India (Chahal and Chohan, 1971) and also by other workers (Hennen *et al.*, 1976) in other countries on cultivated groundnut and wild *Arachis* Spp. In the present findings also, no teliospores were observed on different fresh and stored parts of groundnut plant. Mayee (1987) who failed to show telial stage of the pathogen and reported that, uredospores are the means of dissemination of inoculum in India. The present studies are in agreement with Mayee (1987).

Germination of uredospores of *P. arachidis* at different temperatures

Temperature is most important factor for uredospore germination, infection and further development of the disease. In the present study, maximum germination of uredospores of *P. arachidis* was observed at 25°C (90.81%) followed by 20°C (71.88%) after 12 h of incubation. The higher temperature of 30 °C recorded lower per cent germination of uredospores.

The temperature above 30°C recorded lower germination percentage indicating temperature above 25°C may not be congenial for uredospore germination. This may be due to the production of self inhibitors (Harrison, 1972). The present findings are also in agreement with earlier reports of Fang (1982), Subrahmanyam and Mc Donald (1987), Benagi (1991), Rao *et al.* (1997) and Srikant Das *et al.* (1997). Such studies help in explaining the

occurrence of disease during winter (i.e., December and January when minimum temperatures are near 15) as well as during summer months (i.e., April and May when maximum temperature range from 35-40°C).

Effect of incubation period on germination of uredospores of *P. arachidis*

Germination of infection propagules is an important process in the life cycle of pathogenic fungi and disease development as host penetration and infection depends on this process. More and quick germination also plays a vital role in faster development and spread of the disease. Hence, incubation period required for germination of uredospores of *P. arachidis* was investigated.

Investigation on requirement of incubation period on germination of uredospores revealed that, germination of uredospores started early (25% at 4 h) and reached 70.55 per cent after 8 h of incubation. The maximum germination (93.05%) was observed after 48 h of incubation. Mallaiah and Rao (1979) and Benagi (1991) showed similar results in case of groundnut rust and reported that, maximum germination of uredospores reached at 6 h and there was no further considerable increase in germination after 6 h.

Effect of humidity in relation to disease development

The humidity plays an important role for infection of *P. arachidis*. In the present findings, minimum period of 48 h of higher humidity was required for infection. However, 72 h of humidity was found optimum for maximum infection (98.05%) and for formation of more number of rust

pustule (68.86). Similar results were reported by Cochrane (1958) and Rao *et al.* (1997) in case of groundnut rust.

Effect of age of the plant in relation to infection

Age of the plant is important for development of disease. In the present study, plants of all groups ranging from 10-90 days were found susceptible to rust infection. The maximum intensity of rust was observed on 30-50 days old plants. These findings are in agreement with Mallaiah and Rao (1979), Munde and Mayee (1980) and Patel and Vaishnav (1988) in case of groundnut rust.

Effect of date of sowing on incidence of rust

The date of sowing of crop always plays an important role in disease escape due to unfavourable weather conditions for infection. The results obtained during both years revealed that, the crop sown during the 1st June to 15th June recorded lesser incidence of rust which reflected on obtaining more pod and haulm yield of groundnut compared to the crop sown during July and subsequent months. The results are similar to Naidu and Chandrika, (1997), who reported that, early sown crop suffered least due to low inoculum potential whereas late sown crop suffered more because of ready availability of inoculum built in early sown crop. Similarly, Srikant Das *et al.* (1999) reported that, sowing of groundnut during the month of June minimized the incidence of rust, there by helped to prevent infection and enhance the yield levels.

Aerobiology

Studies on aerobiology of the pathogen are important in order to forecast the occurrence of disease and in devising supervisory management

practices. In the present investigation, the atmospheric uredospore load of groundnut rust trapped in spore trap and disease appearance in the trap nurseries during *Kharif* 2002 and 2003 were studied which helped to assess the time lag between the spores caught in spore trap and pustule appearance on the host in trap nursery.

In order to find out the uredospore load, several techniques have been used from simple glass slide (Mehta, 1940) to Burkard volumetric spore trap (Kulkarni and Ramakrishnan, 1977). In the present study, the vaseline coated glass slide kept in stationary aeroscope was used to catch the uredospores of *P. arachidis.* Similar technique has been used earlier to trap the uredospores of *Puccinia recondita* f. sp. *tritici* (Nargund, 1989), *Puccinia arachidis* (Benagi, 1991) and *P. pachyrhizi* (Hegde, 2001). Based on the data collected on the date of disease appearance in trap nurseries of different locations the possible pathway of *P. arachidis* was traced out. However, this needs further confirmation.

During 2002, the disease spread from Raichur to Gangavati and Gulbarga directly, subsequently the disease was observed in Bijapur, followed by Hagari, Bidar, Annigeri, Dharwad and Arabhavi. On the other hand during 2003, the disease outbreak observed first at Raichur, then spread to Gangavati, and subsequently appeared in Gulbarga, Bijapur, Hagari, Bidar, Annigeri, Dharwad and Arabhavi. Thus the observations revealed that Raichur as one of the foci of infection which helps in further spread of the disease and makes a way to conclude that, uredospores of *P. arachidis*

probably travelled along with the wind current in south or south western direction from Raichur.

The study conducted during 2002 and 2003 thus confirmed that, Raichur acted as a source of inoculum and 'hotspot' of groundnut rust. This finding was strongly supported by Benagi (1991) who opined that Raichur served as 'hot spot' for *P. arachidis* .

Effect of weather factors on development of spore load of *P. arachidis*

The study on development of spore load of *P. arachidis* was carried out at RARS, Raichur and presented on weekly average in terms of standard week with meteorological data.

Air sampling was carried out during 2002 indicated that, the first appearance of spore load in the atmosphere was recorded after 40 days of sowing and maximum spore counts were observed during August and September. While, during 2003 the first appearance of uredospore was noticed at 37 DAS and maximum number of uredospores were also recorded during August-September as observed in 2002. The favourable weather conditions such as temperature and rainfall were prevailed during these months.

The variation in disease appearance in different localities may also be attributed to the prevailing of favourable weather (microclimate) conditions. Mallaiah and Rao (1982 and 1987) reported that, uredospores were dispersed very efficiently by air. Air borne concentration follow the pattern of field disease incidence and can be used to assess the severity. At Raichur, first

HISTOLOGICAL AND HISTOCHEMICAL STUDIES

The studies on histological observations of diseased and healthy leaf tissues revealed that, microtome sections of healthy leaves showed thick and intact epidermal layer with cylindrical palisade and parenchyma cells. Whereas, in diseased leaf microtome sections, the epidermis was thick but not intact. The cells of leaves were completely destroyed wherever pustules are noticed. Kaur and Dhillon (1988) observed collapsed epidermal cells in groundnut leaves infected by *C. arachidicola*

In the present investigation, histochemical studies revealed that, the concentration of polysacharides, proteins and nucleic acids differed between healthy and diseased leaf tissues. Healthy tissues exhibited medium to rich concentration of polysacharides, proteins and nucleic acids, while the reduction of insoluble polysacchardies, total phenols and nucleic acids in diseased leaf tissues was observed during the present study under report. The pathogen depleted the host leaf tissues of these important metabolites due to fast degradation *i.e.,* varied metabolism. The histochemical localization revealed, gradual depletion of polysaccharides, proteins and nucleic acids from the diseased groundnut host tissue infected by *Cercospora arachidicola* (Kaur and Dhillon, 1988) and Vijaykumar (1990).

MECHANISM OF RESISTANCE

Physiological basis of resistance

The static anti-infectional structures *viz.,* thicker leaf cuticle, thicker epidermal cell layer and minimum number of epidermal cells per mm. The present investigation revealed, less number of epidermal cells per mm and increased epidermal cell layer thickness and cuticular thickness in resistant

and moderately resistant varieties than susceptible varieties. These act as first line of defense barrier to prevent invasion of pathogen along with cuticular wax.

These results are in agreement with the findings of Mayee and Apet (1995) who reported that, varieties of groundnut resistant to leaf rust had thicker epidermis cum cuticle. Bhat Tanmai (1997) reported that, groundnut varieties resistant to late leaf spot were characterized by more number of epidermal cells and epidermal thickness compared to susceptible ones. Thus, these histological parameters act as the physical barrier for the entry of the pathogen imparting resistance to wheat genotypes.

In almost all plants, stomata serve as avenues for the entry of various pathogens. If the stomatal number per unit area is less, the pathogens that penetrate through stomata will be difficult. The varieties having this property mentioned above, show resistance to pathogens.

The present investigation indicated that, the stomatal frequency was higher in susceptible varieties. More number of stomata were recorded on abaxial surface than that of adaxial surface of leaf which indicates that, these act as main avenue for the entry of the pathogen into leaf tissue. The size (length, breadth) of stomata was also more in susceptible varieties as compared to resistant and moderately resistant varieties. Susceptible varieties recorded higher frequency and size of stomata which provides higher opportunity for penetration by these pathogens and results in high disease severity than resistant ones. These results are in agreement with studies conducted by different workers (Mayee and Apet, 1995, Mayee and Suryavanshi, 1995 and Benagi, 1995). They reported that, in crop like groundnut the frequency and size of stomata were significantly lower on

catch of spore was recorded on 30-7-2002 and 25-7-2003 for 2002 and 2003, respectively, where in weather conditions during the previous week were maximum temperature range of 35.1-36.9°C and minimum of 23.0-24.2°C and morning relative humidity of 73.4-84.9 per cent followed by rainfall of 1.2 to 4.4 mm were recorded. However, this needs to be confirmed with further studies on epidemiology of groundnut rust taking into consideration the spatial relation with nearby places.

The present investigation also showed that, uredospores were present in atmosphere well in advance (6 to 8 days) of actual appearance of rust on the host. Feakin (1973) classified groundnut rust *P. arachidis*, as airborne disease and opined that aerial dissemination is of paramount importance for groundnut rust as the uredinial stage is the only stage of *P. arachidis* found in most parts of the world. Similar observations were made in cereal rusts (Mehta, 1940 and 1952, Nargund, 1989), in groundnut rust Benagi (1991).

More number of uredospores were trapped during August and September during both the years. Thus, it is concluded that, maximum uredospores were observed in August and September which coincided with the critical stages of infection to *P. arachidis* i.e., at pod formation and development stages. The results are supported by the work of Mayee and Ekbote (1983) who recorded high spore counts of *P. arachnids* in September at Parbhani in Maharashtra.

In the present study, the correlation and multiple linear regression analysis between spore load of *P. arachidis* and weather parameters indicated a higher negative correlation between morning and evening relative humidity

during 2002. While, during 2003 the correlation coefficient between spore load and weather was non significant but the rainfall indicated positive relation where as the temperature and relative humidity were negatively related. Similar results are reported by Galgunde and Kurundkar (2002) who reported that temperature and rainfall were found to influence the deposition pattern as indicated by correlation analysis. Further, he reported that humidity and temperature were negatively correlated, whereas rainfall was positively correlated with the incidence and intensity of rust of groundnut.

The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is, $Y = 224.30-2.21X_1-1.73X_2-0.76X_3-0.84X_4+0.21X_5$. With the step down procedure, only one variable *i.e.*, minimum temperature (X_2) was eliminated and final equation fitted to the data is $Y = 170.48-2.04X_1-0.46X3-1.14X_4+0.25X_5$. hence, it is evident from the data that all weather factors influence the spore load of *P. arachidis* to the extent of 66 per cent, while significant weather factors to the extent of 63 per cent.

Effect of weather parameters on development and spread of disease

Environmental factors decide the epidemics of groundnut rust. The environmental factors like temperature, relative humidity and rainfall are important for disease development and these environmental factors are being used to forecast disease severity. Further, the knowledge of weather conditions for the development and spread of disease is important to organize Agro Advisary Services (AAS) for the farmers to take up timely control measures.

During 2002, the rust symptoms were first observed on 31st standard week when the crop was at 46 DAS. The severity increased slowly and reached the incidence of 88.20 per cent when the crop was at pre-harvesting stage. During the week, maximum temperature of 33.6°C and minimum temperature was 22.4°C with morning relative humidity of 82 per cent followed by 81 mm rainfall. During 2003, the rust symptoms were first observed on 31st standard week, when the crop was at 44 DAS. The rainfall of 1.6 mm with minimum temperature of 23.6 and maximum temperature of 33.1°C, morning relative humidity of 84.6 per cent was prevailed during previous week. Severity increased slowly and reached maximum incidence of 80.10 per cent when the crop was at harvesting stage. The favourable conditions such as rainfall of 66.6 mm with 89.6 per cent morning relative humidity were noticed during the period.

The data on both the years indicated 31st standard week was highly favourable for first appearance of disease. The weather factors played an important role in the initiation and further spread of disease. It gives information to design supervisory control measures of disease in order to get expected pod and fodder yield.

Krishnaprasad *et al.* (1979) reported that, intermittent rains with mean relative humidity above 87 per cent favoured disease initiation. Rust development was proportionately better with every increment of the time of free water availability (Munde and Mayee, 1980). Patel and Vaishnav (1989b) reported that severe rust infection was associated with relative humidity 74-89 per cent and 10-13 mm rainfall during the preceding week. Lokhande *et*

al. (1998) reported that, rain fall of 200 mm were congenial for rust disease development.

The analysis was made to establish the relationship between weather factors and per cent disease index of rust in highly susceptible groundnut variety KRG-1 through correlation and multiple linear regression analysis The relationship between rust PDI and weather factors during 2002 indicated a higher negative correlation between morning and evening relative humidity. During 2003 the correlation coefficient between per cent disease index and weather was non significant but the rainfall indicated positive relation where as the temperature and relative humidity were negatively related. The results are in agreement with Srikanta Das *et al.* (2000) in case of rust of groundnut.

The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is : $Y = 851.45-11.44X_1-3.37X2-1.62X3-4.56X4+0.73X5$. With the step down procedure, only one variable *i.e.*, minimum temperature (X_2) was eliminated and final equation fitted to the data is $Y = 747.05-11.12X1-1.06X3-5.15X4+0.82X5$.

The weather factors influence the disease incidence in KRG-1 to the extent of 80 per cent and significant weather factors to the extent of 79 per cent.

Disease prediction

Weather factors play an important role in disease development when the vulnerable host and virulent pathogen coincide in a situation. Since weather parameters influence the development and further spread of disease, an attempt was made to predict the severity of rust using logistic model. The

observations on per cent disease index data followed the pattern of normal curve during both the years. Hence the development of disease was in logistic form. The logistic model developed for the *Kharif*, 2002 and *Kharif*, 2003 are as under.

$$\hat{Y}_t = \frac{100}{1 + e^{0.952-0.193\ t}} \quad \text{for } \textit{kharif 2002} \text{ with } r = 0.98.$$

$$\hat{Y}_t = \frac{100}{1 + e^{\ 1.157-0.234\ t}} \quad \text{for } \textit{kharif } 2003 \text{ with } r = 0.99.$$

The models had high coefficient of determination values with 98 and 99 per cent during 2002 and 2003, respectively. Since the coefficient of determination is 98 per cent, it is appropriate to employ the logistic model for estimating the development of rust infection. Similar logistic models were developed by Benagi (1995) to estimate the development of late leaf spot of groundnut.

STANDARDIZATION OF INOCULATION TECHNIQUES

In the present study, stapler method of inoculation was found to be most efficient in getting highest disease severity (74.02%) with minimum incubation period (7.5 days) followed by spraying (64.50% and 8.25 days) and dusting (62.13% and 8.5 days). These findings are in agreement with Dadke (1996) where in he reported that, stapler method of inoculation was found to be most effective and convenient for screening of soybean genotypes. Thus, stapler and spraying methods can be used in evaluating groundnut genotypes for rust resistance and other studies.

abaxial surface of leaves of resistant varieties against leaf spot and rust diseases. They reported that the number and size of the stomata are important characters of the leaf in relation to resistance or susceptibility of the plant to many foliar pathogens.

The natural protective covering of the epidermal cells of leaves of higher plants consists of the cuticle with its waxy coating. The waxy cuticle reduces the adherence of water and prevents the formation of infection droplets. The waxy layer besides offering a mechanical barrier which cannot be rendered soluble by the enzymatic action of the germination tubes of the fungi seems to contain substances which inhibit bacterial, fungal and insect attack (Chibnall and Piper, 1934).

The present findings indicated that, resistant varieties *viz.*, GPBD-4 and Dh-22 (Red) showed maximum wax content in addition to the increased wax content as age of the varieties advanced from 25 to 75 DAS. While, the least wax content was observed in susceptible varieties *viz.*, KRG-1 and TMV-2 and it was decreased further as the age advanced from 25 to 75 DAS.

Similar results have been reported by Benagi (1995) who reported that, the wax content was least in susceptible varieties than that of resistant variety of groundnut infected by *C. arachidicola.*

Biochemical basis of resistance

In recent years, it is becoming increasingly evident that, several natural and induced defense mechanisms operate in host plants against different diseases. One such defense mechanism is the presence of certain compounds inhibitory to the pathogen. Some times, the host plant is induced to synthesize these compounds on infection. Analysis of biochemicals

in selected resistant and susceptible varieties was carried out to understand their role in resistance/ susceptibility of varieties.

In general, the infection by some pathogens brings changes in respiratory pathway and photosynthesis which are the vital processes taking place inside the plant and leading to wide fluctuations in sugars (Jayapal and Mahadevan, 1968). In susceptible varieties, disease development was more whereas, the mean sugar content come down at later part of the crop growth. This indicated the utilization of these sugars by the invaded pathogens for their nutrition. Such nutritional utilization of sugars by the invading pathogens has been reported earlier also (Krog *et al.,* 1961).

In the present investigation, diseased leaves of different varieties showed more total, reducing and non-reducing sugar content compared to healthy leaves. Further, when we compare sugar content within varieties, the sugars were more in resistant and moderately varieties than susceptible ones. This could be either due to (i) response of the host to infection resulting in increase in reducing sugar (ii) part of that may be utilized by the pathogen, (iii) interference by the pathogen in the amylolytic activity. In the present findings, resistant genotypes recorded higher sugars and these results were in confirmation with the findings of Subrahmanyam *et al.,* 1976; Siddaramaiah *et al.,* 1979b; Ekbote and Mayee, 1983; Bhat Tanmai, 1997.

Among all the biochemical components, phenols stand out as most important components in imparting resistance to several plant diseases. High concentration causes an instant lethal action by a general tanning effect while, low concentration causes gradual effect on the cellular constituents of

the parasite. If the concentration does not occur in toxic level, the inhibition will be obviously slow. Besides, the pathogens readily detoxify low concentrations of the toxicant rather than high concentrations (Dasgupta, 1988).

In the present investigation, phenol and orthodihdroxy phenol contet were more in healthy leaves compared to diseased leaves. Further, resistant and moderately resistant varieties recorded high amount of these biochemicals than susceptible ones. The high phenolic and orthodihdroxy phenol content in resistant varieties may be due to more sugar as it acts as precursor for synthesis of phenolics. This is in agreement with the findings of Ekbote and Mayee (1983) who have reported, an increasing trend in total phenolics in groundnut varieties which are resistant to rust. Further, they have attributed the disease resistance to the capacity of plant to accumulate phenols at a faster rate. Similar results were also reported by Reddy and Ravindranath (1988), Velazahan and Vidyasekharan (1994) and Kumar and Balasubramanyan (2000).

The protein biosynthesis of the host is widely assumed to be significant feature of pathogenesis, particularly during incompatible reaction. Quantitatively speaking, the total protein synthesis is much enhanced in the healthy tissues around the infected tissues. This additional protein considered to be entirely of host origin (Dasgupta, 1988). In the present findings healthy leaves of both resistant and moderately resistant varieties recorded more of soluble protein than the diseased leaves of susceptible ones.

These are in agreement with Patel and Vaishnav (1986) and Narayan Reddy and Khare (1988) in groundnut rust

STUDIES ON VARIABILITY IN *P. arachidis*

The studies on variability in *P. arachidis* has a greater significance in breeding varieties for resistance against rust. Hence, attempts were made in the present investigation to study the variation in morphological characters of different isolates and their differential reaction on selected host differentials.

Studies on morphological characters of isolates

The investigations on morphological characters are important in studying the variability of pathogens. In the present investigation, it was found that, there was no variation in respect of colour of pustule produced by all isolates. All the 23 isolates produced brown coloured pustules. However, there was little variation in the shape and size of pustule. Out of 23 isolates, 15 isolates produced circular pustules, while in eight isolates round ellipsoidal pustules were observed.

Similarly, all isolates produced brown coloured uredospores. But, little variation was observed with respect to shape and size of uredospores. Out of 23 isolates, 17 produced ellipsoid shaped uredospores, while obovoid shaped spores were observed in six isolates. Hence, in the present study, not much morphological variations among the isolates was seen and similar results were reported by Patil (1996) in sunflower rust.

Studies on variability in *P arachidis*

Attempts were made in the present study to select host differential genotypes and to find out variability if any in *P. arachidis*. In this direction, initially 40 genotypes from germplasm were selected and seven genotypes *viz.*, Dh-22 (Tan), Dh-22 (Red), Dh-53, ICGV-91116, R-9227, R-2001-1 and JL-24 were selected as proposed set of differential hosts for studying variability of *P. arachidis*.

As opined by Kalekar (1983), for developing a set of standard differentials, inclusion of several varieties showing similar reaction was not desirable and selection of few genotypes which exhibit a set of reactions against the different rust cultures was more appropriate. Thus, it was proposed to have five varieties resistant, one moderately resistant and one susceptible. Accordingly, five entries *viz.*, Dh-22(Tan), Dh-22 (Red), Dh-53, R-9227 and R-2001-1, while, ICGV-91116 and JL-24 were moderately resistant and susceptible, respectively were selected during the present investigation.

The studies on physiologic specialization revealed that, all the isolates inoculated on proposed host differentials did not behave differentially in producing the disease reaction. Out of 23 isolates inoculated, 11 isolates produced "+" type by infecting all differentials tested, while 10 isolates produced both "–" and "+" infection types. Among them, Khargone isolate was least virulent by infecting only four differentials *viz.*, Dh-22 (Tan), Dh-53, ICGV-91116 and JL-24, while Aliyarnagar and Coimbatore isolates infected five differentials, but did not produce "+" type infection on Dh-22 (Red) and R-

R-9227. But, all the isolates produced "+" type infection on highly susceptible national check genotype, JL-24.

The results indicated that, there was a little distinct variation in the pathogenicity of different rust isolates to the host differentials tested and this little variation was quite convincible on the background that, the rust isolates were obtained from widely distinct locations and from different cultivars. It was attempted to correlate colour, shape and size of both pustule and uredospore of isolates with virulences under study. These, however did not correlate. The findings are in agreement with Kalekar (1983), who made an attempt to select the host differential genotypes and to study physiologic forms in groundnut rust cultures. He selected 15 genotypes of groundnut as differentials and reported that, all 10 rust cultures behaved differentially. Among them, Pune culture was most virulent and Aurangabad culture was least virulent. He also reported that, the shape, size, colour etc. of uredospores of isolates tested did not correlate with the virulence.

In the present study, as such there was no much variation in the reaction of isolates tested except the difference in reaction of few isolates indicating variability of *P. arachidis.* This may be due to thermosensitivity of these isolates collected from different agroecological zones. Munde and Mayee (1979) reported that, different thermosensitivity of three isolates collected from different agroecological zones of India when inoculated on leaves of SB-IX genotype. Bromfield and Cevario (1970) collected different isolates *viz.*, PR 1-66 and Tex. 2-67 from two widely separated geographical sites and observed that accession PI-314917 and PI-315608 were physiologically

resistant to both the cultures, but they could not be separated into two physiologic races on the basis of reaction.

On the other hand, Hammons (1977) supported existence of physiologic forms in *Puccinia arachidis* on the basis of variation in reaction between two rust isolates. Similar observations were also noticed by Mayee *et al.* (1979) on the basis of variation in reaction on the same genotypes exposed for two years. When the same set of genotype was subjected to screening for two years, some genotypes showed resistances for one year and susceptible reaction in the second year and *vice versa*. This variation in reaction was attributed to existence of physiologic forms of *Puccinia arachidis*.

Hence, the present investigation has shown some variations in rust isolates. Cook (1972) who stated that, *P. arachidis* probably exists in more than one racial form. Nevertheless, the number of isolates being limited and they could not be designated as races until confirmation by including larger pathogen population originated from different locations and preferably from distant host genotypes. Further, it cannot be attributed that, the observed little variation in some isolates as the existence of physiologic forms. The pathogenic variability in rust of groundnut has neither been unequivocally confirmed nor completely ruled out. However, it is further reported that, the pathogen population has become well adopted to certain host populations under diverse environmental conditions. (Mayee *et al.*, 1979). However, it is possible that, there may be existence of ecotypes in rust isolates as pointed out by Mayee (1987). He planted set of 196 groundnut genotypes comprising resistant, moderately resistant and susceptible reactions at four locations in

Maharashtra and found that, no major differences in the level of resistance, but there was a variation in AUDPC for genotypes indicating the possibilities of ecotypes in the rust population. Hence, the little variation in the present study has shown the possibility of existence of races in *P. arachnids.* However, it may be confirmed through recent molecular techniques.

SLOW RUSTING MECHANISMS IN GROUNDNUT GENOTYPES

In the absence of desirable level of resistance, cultivars developing disease at a slower rate are important to achieve desirable yields. Slow rusters are characterized by a lower 'r' value compared to susceptible genotypes under the same set of conditions. This type of resistance is preferred since these genotypes allow certain amount of disease to develop, reduce selection pressure on the pathogen and prevent appearance of new virulent rust strains taking upper hand. Such cultivars remain effective for a longer period (Hooker, 1967). Various mechanisms such as reduction in penetration, infectability, pustule size, pustule expression, spore deposition and increase in latent period and sporulation are responsible for slow rusting (Van der Plank, 1968).

Percent Disease Index (PDI)

The slow rusting mechanism was studied in 21 groundnut genotypes. Of the 21 genotypes tested by assessing PDI at different intervals starting from 47 DAS, 11 genotypes showed 14.44 to 20.37 per cent disease index at 47 DAS and ended up with the 48.52 to 91.48 per cent disease index at 82 DAS. The genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 showed lower

disease severity and these may be considered as slow rusters. Van der Plank (1963) suggested to measure the disease severity several times from beginning to the end of the epidemic to assess slow rusting mechanism in compound interest diseases like rusts. Many workers have employed per cent leaf area covered by pustules to distinguish fast and slow rusting genotypes in cowpea rust (Chandramouli, 1992 and Hegde, 2001).

Rate of disease development (r)

The apparent infection rate "r" was calculated by using the formula proposed by Van der Plank (1963) and it is being widely used to reorganize partial resistance or slow rusting type of resistance (Luke *et al.*, 1975 and Gupta and Singh, 1982). The results on rate of infection revealed that, the lowest average 'r' was observed in Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1. The apparent rate of infection "r" varied widely but it was not consistent for a given genotype. This parameter is not a clear indicative of slow rusting. These observations are in agreement with Wilcoxson *et al.* (1975), Nargund (1989), Chandramouli (1992) and Patil (1996), who have pointed out that "r" values were not as useful as AUDPC values in studying the slow rusting mechanism. These inferences are in conformity with the findings of Raju and AnilKumar (1990) and Chandramouli (1992).

Area Under Disease Progress Curve

This parameter has been used by Wilcoxson *et al.* (1975), for comparison of rate of development of black stem rust in wheat genotypes. AUDPC and 'r' values were used for comparing slow rusting ability. 'r ' values

coupled with AUDPC will give clear cut information regarding slow rusting mechanism. It was concluded that, AUDPC value in the genotypes were distinct and consistent from trial to trial. In the present study also the genotypes differed distinctly for AUDPC values.

The genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 registered lowest AUDPC values. These genotypes had few pustule number, small pustule size and extended latent period compared to other genotypes which possessed relatively longer latent period, few pustules and small pustule size. Thus based on the values, the above said genotypes could be termed as slow rusters. Nargund (1989), Chandramouli (1992) and Hegde (2001) observed lower values of AUDPC in resistant and higher values in susceptible genotypes of wheat, cowpea and soybean rusts, respectively. Hence, 'r' should be coupled with AUDPC values to arrive at better conclusion in the mechanisms of slow rusting.

Latent period

In the 21 genotypes of groundnut studied, the genotypes namely Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 recorded significantly different latent period compared to rest of the genotypes. The differences ranged between 6.2 days to 16.27 days. The differences were largely due to the genotypes, which exhibited the symptom production at different stages *viz.*, peg and pod formation stage. As the groundnut crop season was 90-105 days by which rust could complete 6 to 7 uredospore to uredospore cycles. As the latent

period was less, it indicated more number of times multiplication of uredospores and *vice versa.*

Thus, this component revealed that, the genotypes with short latent period had more number of rust cycles with the multiplication of uredospores up to 10^6. Further, it was reflected in the maximum PDI and AUDPC recorded by those genotypes. While only 10^1 multiplication of uredospore was possible in the genotypes with late or extended latent period which showed reduced PDI and AUDPC. This suggested the reduced initial inoculum load on the genotypes which was responsible for imparting the partial resistance. Further, Chandramouli (1992) while working with cowpea rust, noticed similar kind of difference in latent period between fast rusting and slow rusting genotypes. Habtu and Zadoks (1995) and Hegde (2001) also made similar observations, where in the latent period extended from 9.40 to 18.60 days and 9.17 to 16.22 days in bean and soybean genotypes, respectively. They opined that the extended latent period played a major role in partial resistance. Reddy and Khare (1988) reported that, resistant cultivars had longer incubation period, lower pustule densities and smaller pustules than susceptible ones in case of groundnut rust.

Number of pustules/sq. cm.

Differences in pustule number among cultivars were found in most patho systems as reported by Groth and Urs (1982) and Statler and McVey (1987). In the present study, highly significant differences for pustule number were recorded. The genotypes which had recorded extended latent period (14.27 to 16.27 days) *viz.,* Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260,

ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 exhibited uredial density of 25.84 to 36.03 per sq. cm of leaf area. Whereas the genotypes with shorter latent period had higher number of pustules (44.10 to 70.57/sq. cm) which in turn reflected in high AUDPC and PDI. Reddy and Khare (1988) reported similar results of lesser pustule number in resistant genotypes of groundnut against *P. arachidis*. The results were further supported by Habtu and Zadoks (1995) and Chandramouli (1992). They suggested that low pustule number per unit area is an important component of slow rusting mechanism.

Pustule size

The importance of pustule size as an index of slow rust resistance was reported by Webster and Ainsworth, (1988) and Habtu and Zadoks (1995). In the present investigation, the genotypes with small pustule size *viz.,* Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 over other genotypes recorded very low AUDPC and PDI. While the genotypes with higher pustule size have reflected in increased AUDPC and PDI. The production of bigger size uredia with increased number of days after inoculation may be attributed to the availability of healthy area for increase in the size, whereas in the slow rusting genotypes the size of the uredia may be small or sometimes reduced with increased days after inoculation may be attributed to the increased number of uredia which lead to the non availability of healthy area to cover bigger size pustules. Reddy and Khare (1988) reported smaller sized pustule with increased density in rust resistant sunflower and groundnut genotypes.

Number of uredospores/pustule

Reduced number of uredospores per pustule in some genotypes has been considered as an important component of slow rusting (Sharma *et al.,* 1986). In the present investigation, sporulation capacity was found minimum in slow rusters *viz.,* Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 and maximum in genotypes with bigger sized uredia which in turn manifested in high AUDPC and PDI. Eleven genotypes produced more than 3000 uredospores per pustule. Amount of uredospore production mainly depends on the number and size of the pustule (Sharma *et al.,* 1986). Habtu and Zadoks (1995) were also of the opinion that sporulation capacity was strongly correlated with pustule size.

On the basis of PDI, ' r ', AUDPC, LP, pustules per sq. cm., pustule size and number of uredospores per pustules, the genotypes namely, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 were considered as slow rusters and may be cultivated in groundnut rust endemic areas.

COST EFFECTIVE INTEGRATED DISEASE MANAGEMENT

In the present investigation, it is evident that, three consecutive application of hexaconazole, difenconazole and propiconazole have reduced the disease severity of rust upto 85 DAS, which reflected on more pod and haulm yield of groundnut. The findings are in agreement with Subrahmanyam *et al.* (1990) who reported that, hexaconazole gave the best control of rust. Benagi (1991) reported that, groundnut rust can be controlled

effectively by spraying with propiconazole with higher pod and haulm yields. Similar findings were reported by Jadeja *et al.* (1999) who found that, three sprays of hexaconazole at 15 days interval gave best result among other fungicides tested in controlling the disease followed by difenconazole.

Further, Neem seed kernel extract in the middle of the fungicides also showed their effectiveness in controlling the rust to a greater extent. Combination of hexaconazole alternated with NSKE (H-N-H) showed lesser PDI followed by combination of D-N-D and P-N-P with higher pod and haulm yields. This clearly indicated that, addition of Neem seed kernel extract in between spray sequence is more useful in reducing disease and also enhancing yields. The spray combination of H-N-H reduced one spray of hexaconazole thus increasing benefit cost ratio as well as gave insurance against development of resistance by the pathogen to fungicides.

Benefit cost ratio gives an information on whether the technology could be adopted in the farmers fields or not. Hence, cost benefit ratio is an important parameter for recommendation of any treatment for successful control of plant diseases. In the present study, though the treatments containing three sprays of difenconazole and propiconazole and the Neemseed kernel extract in between these two triazoles gave significant control of rust, but the maximum cost benefit ratio of 6.09 was realised in treatments containing three sprays of hexaconazole (0.1%) followed by H-N-H (4.58). This clearly indicated that, the inclusion of Neem seed kernel extract in the middle of spray schedule is more useful not only in reducing the cost of protection but also gave higher benefits as compared to Neem seed kernel

extract included either in propiconazole or difenconazole or Chlorothalonil and control treatment in addition to giving insurance against development of resistance by the fungus against hexaconazole.

Usman *et al.* (1991) used different Neem products, *viz.*, Neemoil, Neem seed kernel extract and Neem cake extract in the management of rust and late leaf spot of groundnut. They recorded higher benefit cost ratio in Neemkernel extract applied treatment in addition to reducing the incidence of rust and late leaf spot. Further, the fungicidal property in the Neem plant part is due to terpenoid substances. More than 50 terpenoids have been isolated from Neem tree (Jones *et al.*, 1989).

Spraying of Neem leaf extract in combination with recommended fungicides recorded numerical superiority in reducing leaf spot and rust incidence in groundnut (Shivashankar and Kadam, 1993). Benagi (1995) revealed that, Chlorothalonil application on 30th and 50th day after sowing (DAS) and either Tridex leaf extract or Neem kernel extract (5%) spray on 45 DAS gave better pod yield with minimum disease severity. Benefit cost ratio of 7.48 and 6.48 were obtained in CTC and CNC combination of spray schedules, respectively. Patil (1996) suggested that, rust of sunflower can be managed effectively with a spray schedule of propiconazole (0.1%) and *Amaranthus* leaf extract or Neem kernel extract (5%) with higher BCR. Whereas, Jadeja *et al.* (1999) reported that, hexaconazole treated plots gave a 71 and 87 per cent higher pod and haulm yields, respectively than an untreated control with highest net return of Rs 9793/- per ha.

Hence, spraying of hexaconazole (0.1%) at 45 and 65 DAS and Neem seed kernel extract (0.5%) at 55 DAS could be considered as an effective management practice to control groundnut rust. Integration of slow rusters (Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1) coupled with H-N-H spray schedule under less disease pressure and H-H-H spray schedule under high disease pressure will be effective in reducing the disease pressure and enhancing yields of groundnut. The studies indicated that groundnut rust can be effectively managed by following Integrated Disease Management practices.

Future line of work

1. Qualitative and quantitative estimation of spore load of *P. arachidis* and validation of forecasting models through air sampling by using Burkard volumetric spore trap.
2. Variability with respect to virulence of the pathogen needs to be investigated by collecting large number of isolates from different agro ecological regions through molecular techniques.
3. The biochemical aspects of slow rusting of groundnut varieties needs to be properly understood.
4. Collateral hosts needs to be critically observed during off season for the survival and perpetuation of uredospores of *P. arachidis*.
5. Further studies are required to know the role of teliospores in the epidemiology of groundnut rust in India.
6. Effect of weather parameters on the spore load of *P. arachidis* and disease incidence may be studied through correlation and regression analysis need to be continued.
7. Utilization of slow rusting genotypes in disease resistant breeding programme and molecular characterization of genes responsible for resistance in the resistant varieties.
8. Multilocational trials may be conducted to test the efficacy of fungicide and Neem seed kernel extract in the management of rust of groundnut.

SUMMARY

VI SUMMARY

Groundnut rust caused by *P. arachidis* Speg. is found world wide. In recent past, it has become a major menace for groundnut cultivation in India in general, and Northern Karnataka in particular. Hence, studies on epidemiology, crop loss assessment and management aspects of the disease were carried out and results thus obtained are summarized here under.

Survey conducted during *kharif* 2002 and 2003 revealed that, the average disease severity was found more in Raichur district (65.50%) followed by Gulbarga (60.26%) and Koppal (59.53%) and least in Dharwad (37.31%). Maximum disease severity of 73.40 per cent was recorded in Arakera followed by Chandrabanda (72.09%) and Jangamarahalli villages (70.75%) of Raichur district. Lower disease severity (23.99%) was recorded in Halaharti village of Gulbarga district followed by Narendra (33.54%) and Manokod village (36.12%) of Dharwad district.

The observations on loss estimation revealed that, comparatively lower disease index with increase in pod and haulm yield and also maximum BCR was recorded in plots receiving three to six sprays of hexaconazole in a susceptible cultivar KRG-1 and two to six sprays of the same in moderately resistant variety K-134. Maximum benefits were obtained from the plots receiving three and two sprays of hexaconazole in KRG-1 and K-134, respectively.

The average pod yield loss of 40.20 and 34.00 per cent was observed in susceptible (KRG-1) and moderately resistant (K-134) varieties, respectively. Similarly, the loss in haulm yield (47.04%) was more in KRG-1 than K-134

(32.11) variety. Yield loss models were developed using PDI as input variable and are given below.

KRG-1:

Y= 30.688 – 0.808 PDI with r=0.85 (*Kharif* 2002)

Y= 23.547- 0.310 PDI with r=0.76 (*Kharif* 2003)

K-134 :

Y= 31.642- 0.823 PDI with r=0.96 (*Kharif* 2002)

Y = 23.789 – 0.341 PDI with r=0.79 (*Kharif* 2003)

Viability of uredospores of *P. arachidis* was observed up to 40 days at room condition (20-25°C) followed by tree shade conditions (15-20°C). Under field conditions (25-28°C), viability of uredospores was noticed up to 20 days. Maximum per cent germination of uredospores was recorded at 25°C which subsequently reduced at higher temperature levels. The optimum temperature of 25°C was found congenial for maximum germination of uredospores of rust pathogen. The humidity of 78 per cent was found optimum for maximum infection and formation of more number of pustules. Groundnut plants of all age groups ranging from 10-90 days were found susceptible to infection of rust disease. Survey conducted during off-season revealed that uredospores on self sown/voluntary groundnut plants play an important role in survival of pathogen from season to season as telial stage was not present in *P. arachidis*.

The study on date of sowing revealed that groundnut crop sown during the month of June recorded lesser disease incidence of rust.

Observations on movement of uredospores of *P. arachidis* revealed that, Raichur as one of the foci of infection which is responsible for further spread

of disease. Trap nursery studies indicated that Raichur acted as a source of inoculum and hotspot of groundnut rust.

The studies on effect of weather factors on development of spore load of *P. arachidis* indicated that more uredospore counts were observed during August and September which coincided with the critical stages of infection to *P. arachidis*.

The correlation studies between spore load and weather parameters indicated a positive relation with rainfall. The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is, $Y = 224.30-2.21X_1-1.73X_2-0.76X_3-0.84X_4+0.21X_5$. Minimum temperature ($X_2$) was eliminated with step down procedure and final equation fitted to the data is $Y=170.48-2.04X_1-0.46X3-1.14X_4+0.25X_5$.

The studies on effect of weather factors on development of disease revealed that, 31st standard week was highly favourable for appearance and development of disease. There was a positive correlation between the disease incidence and rainfall. The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is, $Y= 851.45-11.44X_1-3.37X2-1.62X3-4.56X4+0.73X5$. With the step down procedure, only one variable *i.e.*, minimum temperature (X_2) was eliminated and final equation fitted to the data is $Y=747.05-11.12X1-1.06X3-5.15X4+0.82X5$.

The observations on per cent disease index followed the pattern of normal curve during *kharif*, 2002 and 2003 and the development of disease was in logistic form. The logistic models developed for *Kharif*, 2002 and *Kharif*, 2003 are as under.

$$\hat{Y}_t = \frac{100}{1 + e^{0.952-0.193\,t}} \quad \text{with } r = 0.98 \text{ for } \textit{kharif, 2002}$$

$$\text{and } \hat{Y}_t = \frac{100}{1 + e^{1.157-0.234\,t}} \quad \text{with } r = 0.99 \text{ for } \textit{kharif,} \text{ 2003}$$

Among the different methods of inoculations tried, stapler method of inoculation was found to be best with less incubation period and highest PDI followed by spraying method of application of uredospores.

Histochemical studies indicated that, diseased leaves showed low concentration of all the molecules in palisade and spongy parenchyma cells, whereas, healthy leaves showed rich concentration of proteins and medium concentration of polysaccharides and nucleic acids.

Among histological parameters, cuticular thickness, epidermal cell thickness and wax content was more in resistant and moderately resistant genotypes than susceptible ones, Whereas, number and size of epidermal cells and stomata was more in susceptible varieties.

The biochemical studies indicated that, diseased leaves of resistant and moderately resistant varieties showed more total, reducing and non-reducing sugar contents compared to healthy leaves of different varieties. Further, the sugars were more in resistant and moderately resistant varieties than susceptible ones. The results showed that unlike sugars, phenol, orthodihydroxy phenol and protein contents were more in healthy leaves compared to disease leaves. Within varieties, resistant and moderately

resistant varieties showed more contents of these biochemicals than susceptible varieties.

Hence, studies revealed that higher epicuticular wax, phenols, soluble protein, cuticular and epidermal cell thickness and lesser length, breadth and number of stomata in groundnut genotypes are the reasons for resistance against rust.

Studies on variability of *P. arachidis* revealed that, very little variation in the morphology of pustules and uredospores of 23 isolates studied and as such, there was no much variation in the reaction of these isolates inoculated on seven differentials except the difference in reaction of few isolates.

Based on different components of slow rusting ten genotypes *viz.*, Dh-22 (Red), Dh-22 (Tan), GPBD-4, ICRG-93260, ICRG-93261, K-134, R-8808, R-9214, R-9227 and R-2001-1 were registered as slow rusters.

In the integrated management of the disease, treatments *viz.*, H-H-H followed by H-N-H were found to be effective in managing rust of groundnut and increased pod and haulm yield with maximum BCR. Thus, among the treatment combinations, Neem seed kernel extract intermixed with hexaconazole spray schedule (H-N-H) not only reduced the cost of protection but also gave higher benefits.

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**** Original not seen***

Appendix II. Weekly meteorological data recorded at RARS, Raichur during *kharif*, 2003

Std Week	Month and Date	Temperature		Relative humidity		Rainfall (mm)
		Maximum (° C)	Minimum (° C)	Morning	Evening	
23	Jun. 4 to 10	40.9	26.8	61.1	25.9	0
24	Jun. 11 to 17	38.0	25.6	67.8	37.1	2.4
25	Jun. 18 to 24	37.4	24.7	81.4	51.7	41.6
26	Jun. 25 to 1	36.1	23.6	80.8	47.7	17.3
27	July 2 to 8	33.8	23.6	83.7	46.5	15.0
28	July 9 to 15	34.1	22.8	85.5	55.1	14.4
29	July 16 to 22	36.9	24.2	73.4	49.6	4.4
30	July 23 to 29	33.1	23.6	84.6	55	1.6
31	July 30 to 5	34.4	22.9	79.6	55	10.8
32	Aug. 6 to 12	31.7	23	82.6	60	30.2
33	Aug. 13 to 19	34.8	23.5	75.8	43	4.4
34	Aug. 20 to 26	30.5	22.2	87.1	66	73.2
35	Aug. 27 to 2	33	22.8	78	53	15.2
36	Sep. 3 to 9	33.4	22.2	77	46	0
37	Sep. 10 to 16	34.3	21.9	72.9	44	12.4
38	Sep. 17 to 23	34.2	23.8	71.6	41	0
39	Sep. 24 to 30	31.3	22.6	89.6	60	66.6
40	Oct 1 to 7	33.7	23.0	86	53.7	27.0
41	Oct. 8 to 14	33.0.	21.9	84.4	49.1	15.8
42	Oct. 15 to 21	33.5	22.8	79.7	44.7	2.0
43	Oct. 22 to 28	31.3	19.8	86.4	50.1	6.2
44	Oct. 29 to 4	33.1	22.1	79.9	44.7	0

Appendix I. Weekly meteorological data recorded at RARS, Raichur during *kharif*, 2002

Std Week	Month and Date	Temperature		Relative Humidity		Rainfall (mm)
		Maximum (°C)	Minimum (° C)	Morning	Evening	
23	Jun. 4 to 10	37.1	23.1	82.2	47.2	43.4
24	Jun. 11 to 17	35.1	24.5	82.0	48.4	0.0
25	Jun. 18 to 24	35.7	24.5	82.4	48.0	0.0
26	Jun. 25 to 1	35.1	24.0	82.0	54.5	4.2
27	July 2 to 8	36.2	24.4	78.3	42.0	0.0
28	July 9 to 15	33.8	22.6	84.3	59.5	12.2
29	July 16 to 22	34.0	22.7	85.3	60.4	28
30	July 23 to 29	35.1	23.0	84.9	49.7	1.2
31	July 30 to 5	33.8	23.9	87.3	64.1	20
32	Aug. 6 to 12	29.1	21.8	89.9	75.9	79.8
33	Aug. 13 to 19	32.6	22.9	79.7	52.1	0
34	Aug. 20 to 26	33.2	22.5	78.7	45.3	4
35	Aug. 27 to 2	34.3	24	73.0	49.4	3.4
36	Sep. 3 to 9	34.3	22.6	78.6	43.6	28.2
37	Sep. 10 to 16	34.6	23.4	72.6	45.4	0
38	Sep. 17 to 23	33.6	22.4	82.0	48.1	81
39	Sep. 24 to 30	35.2	23.6	75.9	36.3	0
40	Oct. 1 to 7	36.8	23.7	67.0	30.0	0.0
41	Oct. 8 to 14	33.1	23.3	86.0	60.0	28.8
42	Oct. 15 to 21	32.9	22.6	91.0	51.0	151.6
43	Oct. 22 to 28	32.1	20.4	87.0	42.0	0.0
44	Oct. 29 to 4	30.9	19.5	81.0	45.0	9.0