

**DETECTION, TRANSMISSION AND EPIDEMIOLOGY
OF SORGHUM STRIPE TENUIVIRUS DISEASE
ON SORGHUM [*Sorghum bicolor* (L.) Moench]**

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**DEPARTMENT OF PLANT PATHOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
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OF SORGHUM STRIPE TENUIVIRUS DISEASE
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C E R T I F I C A T E

This is to certify that the thesis entitled "DETECTION, TRANSMISSION AND EPIDEMIOLOGY OF SORGHUM STRIPE TENUIVIRUS DISEASE ON SORGHUM [Sorghum bicolor (L.) Moench]" submitted by Mr. Y.D. NARAYANA for the degree of DOCTOR OF PHILOSOPHY IN PLANT PATHOLOGY of the University of Agricultural Sciences, Bangalore, 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 for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bangalore
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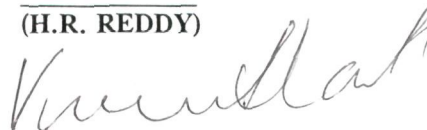
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INTRODUCTION

I INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench] was probably the first domesticated crop in Eastern Africa in the regions of Ethiopia and Sudan. Later the cultivation of sorghum spread throughout Africa, Asia and finally to America and Australia. Today sorghum is the fifth most important world cereal crop following wheat, rice, maize and barley particularly in semi-arid areas of tropics and subtropics (Doggett, 1988). Sorghum has been shown to have highest conservation of sunlight energy to biomass making it a high energy crop.

Sorghum is grown in an area of 49 m ha in the world with an average productivity of 1355 kg/ha (Anon.,1989). India Sorghum ranks first in area (16.5 m ha) followed by China (8.5 m ha), USA (6.2 m ha), Nigeria (6.0 m ha) and Sudan (3.5 m ha). In productivity of sorghum, USA stands first (3541 kg/ha) followed by China (3157 kg/ha), India (864 kg/ha), Nigeria (500 kg/ha) and Sudan (414 kg/ha), (Anon.,1990).

In India sorghum is the third most important cereal crop next to rice and wheat. The major sorghum growing states in India are Maharashtra (6.54 m ha), Karnataka (2.91 m ha), Madhya Pradesh (2.10 m ha), Andhra Pradesh (1.94 m ha), Rajasthan (0.98 m ha) and Gujarat (0.94 m ha). In production Maharashtra ranks first (4.67 mt) followed by Madhya Pradesh (1.96 mt), Karnataka (1.89 mt), Andhra Pradesh (1.08 mt), Rajasthan (0.59 mt) and Gujarat (0.55 mt) (Anon., 1991)

In Karnataka, sorghum occupies the first place in area and ranks next to rice in production (Anon., 1990). The area under sorghum was 2.1 m ha with annual production of 1.3 mt during 1990-91. In Karnataka the major sorghum growing districts include Bidar, Bijapur, Gulburga, Dharwar, Belgaum, Bellary, Raichur and Chitradurga showing 97.7 per cent area and contributing 92 per cent of the total production. The average productivity of sorghum in kharif and rabi was 1149 and 535 kg/ha, respectively.

Sorghum diseases are considered to be one of the main constraints in higher grain production. Due to introduction of high yielding varieties and hybrids with diversified genetic makeup, together with changed cultivation practices and cropping patterns, many pathogens like fungi, bacteria and viruses in particular have taken upper hand and act as a limiting factor in higher grain and fodder production.

The first virus disease on sorghum described and identified as sugarcane mosaic virus (SMV) by Brandes and Klapaak (1923). Tarr (1962) reviewed viral diseases of sorghum and reported 15 viruses as pathogenic to sorghum. Later Miller (1966) also published list of viral diseases of sorghum.

The purified sorghum stripe virus (SStV) particles are filamentous with less than 10 nm in width with eight species of nucleic acid containing four ssRNA's and four dsRNA's and serologically related more closely to maize stripe virus on maize grouped under tenuivirus.

The sorghum stripe disease reported in India has been purified, characterised and included in tenuivirus group. In nature SStV is transmitted by the delphacid planthopper Peregrinus maidis (Ashmead). The economic importance of SStV disease, diagnosis, epidemiology, virus-vector relationship, host range, effect on growth and yield, technique to screen sorghum cultivars for resistance have not been investigated.

The present investigations were undertaken to fill this lacuna with the following objectives:

1. Standardization of penicillinase based enzyme linked immunosorbent assay (PNC-ELISA) for detection of sorghum stripe virus (SStV) in the host and the planthopper.
2. Survey for SStV incidence and planthopper population in sorghum in different parts of Karnataka.
3. Symptomatology.
4. Virus-vector relationships.
5. Host range of SStV.
6. Epidemiology of SStV.
7. Effect of SStV on growth and yield of sorghum.
8. To develop effective inoculation technique and
9. Screening of sorghum varieties and hybrids for SStV susceptible/resistance.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The literature pertaining to studies on different aspects of sorghum stripe virus (SStV) disease is reviewed and presented below.

Sorghum [Sorghum bicolor (L.) Moench] is one of the major cereal food crops in the world particularly in areas of high temperature and low rainfall. The first virus disease described on sorghum was sugarcane mosaic virus (Brandes and Klapaak, 1923). Tarr (1962) reviewed the virus diseases of sorghum and identified sugarcane mosaic, maize mosaic, barley yellow dwarf virus, rice stripe virus, freckled yellow stripe disease and maize streak virus. Miller (1966) also published a list of virus diseases that infect sorghum. Teakle (1979) reviewed sorghum viruses and added to the earlier list which include maize dwarf mosaic (Dale, 1964), maize rough dwarf mosaic (Vidaao et al., 1966) cucumber mosaic virus (Wellman, 1934a), peanut clump virus (Dollet et al., 1976), maize chlorotic mottle virus (Castillo and Hebert, 1974), maize stripe virus (Capoor et al., 1968), sugarcane chlorotic streak virus (Eagen, 1965), maize chlorotic dwarf virus (Nault et al., 1976) and barley yellow dwarf virus (Rochow, 1970). Sorghum stunt mosaic virus on sorghum was recently added to the list (Mayhew and Flock, 1981).

Among the virus diseases of sorghum reported in India a stripe virus of sorghum described by Cherian and Kylasam (1937) was transmitted by planthopper Peregrinus maidis. Later Capoor

et al., (1968) reported a serious virus disease of sorghum on cultivar, Maladandi in early 1960 affecting the rabi sorghum in India and found to be transmitted by shootbug Peregrinus maidis.

Chatterjee (1971) described a stripe disease of maize occurring in Maharashtra and the disease was transmitted by Peregrinus maidis but did not infect sorghum, pearl millet, wheat or rice. Seth et al. (1971) reported the first occurrence of streak disease of bajra in India. Seth et al. (1972) demonstrated maize streak on wheat, sorghum, bajra and identified the vector as Cicadulina mbila (Naude.,). Anahosur et al. (1980) reported on sorghum in Karnataka a virus transmitted by the aphid Rhopalosiphon maidis (Brandes.,). Later Garud and Mali (1983) reported virus disease on sorghum, identified, based on physical properties, host range and serological tests as red stripe virus.

Sharma and Payak (1983) reported that the planthopper Peregrinus maidis as an experimental vector of maize stripe virus on maize. The other hosts infected by maize stripe virus include sorghum, sugarcane and wheat. Naidu et al. (1989) reported maize mosaic virus a rhabdovirus on sorghum transmitted by a delphacid vector Peregrinus maidis. Peterschmitt et al. (1991) reported a disease characterized by chlorotic stripe and bands named as sorghum stripe tenuivirus on sorghum in India. The disease was transmitted by planthopper Peregrinus maidis.

2.1 Symptomatology

Capoor et al. (1968) reported a serious disease of sorghum causing chlorosis of leaves, stunting of shoots, early flowering and excessive tillering. They identified it as maize stripe virus vectored by P. maidis. Kulkarni (1973) described and designated two types of leaf symptoms on maize. First type he described as maize stripe virus (MSV) which showed broad yellow stripe or yellowing of the entire leaf with acute bending of the shoot apex and severe stunting. The second type as maize line virus (MLV) which included continuous narrow yellow lines along the leaf veins and did not cause apical bending or stunting and found both viruses transmitted by Peregrinus maidis. Tsai (1975), Gingery et al. (1979) and Greber (1981) described maize stripe virus (MStpV) on maize which caused severe chlorotic striping, streaking with frequent apical bending and the infected plants producing little or no grain formation. Toler (1979) reviewed several viruses and viral diseases of sorghum and symptoms induced by these viruses. Ou (1985) described on rice characteristic symptoms of stripe like the presence of wide chlorotic stripes, chlorotic mottling, diseased plants appeared stunted with reduced tillers, poor heads with malformed spikelets and premature death if infected at early stage of infection. Gingery (1985) reported that the initial symptoms of maize stripe virus on maize are chlorotic spots and streaks on youngest leaves 4 to 7 days after inoculation. As the leaves expand the spots and streaks fuse to form chlorotic bands of variable width. Late infections results in where most of the leaf may become chlorot-

ic. The infected plants remain stunted with acute bending at the apex, Early infection cause death of seedling.

Naidu et al. (1989) from India reported a leaf disease on sorghum characterized by fine discontinuous chlorotic streaks between the veins and the plants infected at early stage were stunted with shortened internodes and produced poorly developed panicles. It is suggested to be an isolate of maize mosaic virus of sorghum. Peterschmitt et al. (1991) reported a sorghum disease from peninsular India, which is characterized by chlorotic stripes and bands. The affected plants were dwarfed with poor or no panicle formation and named it as sorghum stripe disease.

Bradfute and Tsai (1990) described the symptoms produced by maize stripe virus on maize for rapid identification. The symptoms consisted of chlorotic patterns of overlapping circles with distinct margins when magnified ten times. These diagnostic symptoms could be readily found in natural and experimentally infected maize plants.

2.2 Detection of virus in host and vector by ELISA

The enzyme linked immunosorbent assay (ELISA) is by far the most widely used serological technique for detecting plant viruses in host plant and insect vector. Accurate diagnosis of

plant viruses is fundamental to the control of plant viruses for economically important plant viruses.

Saito and Iwata (1964), Kitani and Kiso (1967) employed haemoagglutination test and fluorescent antibody technique for detecting the virus in viruliferous insects on rice plants and found that the methods made possible for the detection of virus in small quantities. Voller et al. (1976a) used enzyme linked antibodies for the detection of two morphologically different plant viruses. The technique is extremely sensitive enabling the assay of viruses at concentration as low as 10 to 100 ng/ml both in purified and crude extracts.

Clark and Adams (1977) demonstrated characteristics of a microplate method for the detection and assay of plant virus using enzyme labelled antibodies. This method enabled the highly sensitive detection of a number of morphologically different viruses in purified and unclarified extracts from infected plants. Since 1977 ELISA has been developed as a powerful tool for the detection of plant viruses in host and insect vectors. Reeves et al. (1978) and Sum et al. (1979) applied ELISA successfully for serological diagnosis of maize dwarf mosaic virus (MDMV) and maize chlorotic dwarf virus (MCDV). A comparison showed that ELISA was 100 times more sensitive than the conventional infectivity test. The technique could detect maize chlorotic mosaic virus (MCMV) upto 115 ng/ml and MDMV upto 1 ng/ml suggesting that ELISA can be used for routine diagnosis. The

detection of potato leaf roll virus could be done by ELISA can for routine indexing for phytosanitary ~~;~~ (Casper, 1977).

Lister (1978) and Koenig (1978) demonstrated that ELISA test can easily detect tobacco ring spot virus (TRSV) or soybean mosaic virus (SMV) in individual seed which may be widely applicable on testing large seed samples of legumes and cereals.

Abdullah et al. (1978) demonstrated the detection of an aphid transmissible strain of cucumber mosaic virus (CMV) in single viruliferous aphid. The results showed that ELISA may be of value for epidemiological studies of aphid borne viruses. Azar and Banttari (1981) compared ELISA and transmission assay for oat blue dwarf virus in aster leafhopper. In the experiment they found that 27 out of 145 (19%) were positive in both assays and in another test 61% was positive by ELISA. The results suggested that the percentage of aster leafhopper carrying viruses after acquisition on infected oats were easily detected by ELISA assay.

Chu and Francki (1982) successfully used ELISA system for the rapid detection of lettuce necrotic yellow rhabdovirus in plant hosts and individual aphid vector. About 50 per cent of the grass samples collected in Indiana during summer of 1980 were infected with barley yellow dwarf virus when tested by ELISA (Fargette et al., 1982).

Mumford (1982) identified beet leafhoppers carrying beet curly top virus acquired from feeding on infected plants or extracts using ELISA. The method has been successfully used to detect virus levels in field populations of beet leafhoppers.

Caciagli et al. (1986) detected subviral particles of maize rough dwarf virus in Laodelphax striatellus(Fall.) vector and in infected maize and barley plants. Subviral particles were efficiently detected by ELISA in individual male and female insects. Of the total insects tested positive to ELISA 15-20% were unable to transmit the virus to host plants. Falk and Tsai (1985) demonstrated that maize mosaic virus (MMV) antigens were detected by ELISA in individual P. maidis after acquisition. It has been shown that all P. maidis which are transmitters showed ELISA positive and confirmed that MMV multiplied in P. maidis.

Francki et al. (1986) reported that 15% of the adult Perkinsiella saccharicida infected with Fiji virus was detected by ELISA and about 6% transmitted the virus. Ammar et al. (1987) studied the interactions of maize mosaic virus and maize stripe virus in their vector P. maidis using ELISA. The results showed, that the concentration of MStpV antigen is higher in plants infected with MStpV alone than together with maize mosaic virus (MMV). It also demonstrated that with P. maidis access to MMV infected plants within 14 days before or after access to MStpV infected plants it significantly reduced the number of insect transmitting MStpV.

Falk et al. (1987) used ELISA to detect the multiplication of MStpV in P. maidis. The results indicated that the 32K protein was detected in both host and vector but it was not detected in P. maidis until 8 days after AAP. The per cent positive P. maidis increases with time indicated the multiplication of MStpV in P. maidis. Hobbs et al. (1987) compared the direct antigen coating (DAC) and protein A coating (PAC) forms of indirect ELISA and compared with double antibody sandwich (DAC) in the detection of three peanut viruses. It was found that the sensitivity of DAC and PAC were comparable to that of DAS under short incubation (1-2 h at 35°C) period.

Eweida et al. (1988) monitored barley yellow dwarf virus (BYDV) in roots and leaves of oats inoculated at 1-2 and 4-5 leaf stages. Virus was detectable 20 h after inoculation in the roots and after 48 h in the leaves when inoculated at 1-2 leaf stage. The virus concentration in roots was 3 to 4 times higher than in leaves. Virus was readily detectable in fresh and dried seeds but seed transmission could not be demonstrated. Tomato spotted wilt virus was also detected by ELISA in 32 of 275 adult and 233 of 527 larval thrips Frankliniella occidentalis (Cho et al., 1988).

Nault and Gordon (1988) used ELISA to demonstrate the maize stripe virus multiplication in its planthopper vector P. maidis. MStpV was detected by ELISA from single planthopper immediately 2 days after acquisition and later on increasing number of insects

at 9, 16 and 23 days after the start of AAP. MStpV was also detected by ELISA from different organs including eggs of viruliferous females. Sudarshana and Reddy (1989) standardized penicillinase based ELISA to detect maize mosaic virus (MMV) in sorghum, peanut mottle virus (PMV) in pea leaf and tomato spotted wilt virus (TSWV) in peanut leaf and found that technique was comparable to those of alkaline phosphatase (ALP) and horse raddish peroxidase (HRP) systems in detecting all the three viruses. The PNC based ELISA provides less expensive means for assaying plant viruses when compared to ALP and HRP. Zeigler and Morales (1990) and Tak^{ashi} et al. (1991) successfully used ELISA to detect rice hoja blanca virus in vector and replication of virus within the vector.

2.3 Survey

The first sorghum virus described as sugarcane mosaic was identified in 1923 by Brandes and Klapaak. Tarr (1962) reviewed and reported a list of 15 viruses and virus like agents infecting sorghum which includes sugarcane mosaic virus, maize mosaic virus, red stripe virus, Fiji disease virus, brome mosaic virus, cucumber mosaic, oat pseudorosette virus, barley yellow dwarf virus, rice stripe virus, maize streak virus. Toler (1977) added several viruses infecting sorghum since 1962, which include maize dwarf mosaic virus, panicum mosaic virus, maize rough dwarf virus, peanut clump virus, maize chlorotic mottle virus, chlorotic streak virus, maize stripe virus and maize chlorotic dwarf virus. The most recent virus disease infecting sorghum was

sorghum stunt mosaic virus from California (Mayhew and Flock, 1981).

Storey (1936) first described maize stripe virus disease in maize (Zea mays L.) in East Africa. He described two types of symptoms one with narrow yellow stripe and the other with broad yellow stripe and both are transmitted by Peregrinus maidis. Chellaiah and Basheer (1966), Rawat and Saxena (1967) reported the importance of P. maidis in South India and found to attack sorghum, bajra, maize, Sorghum halepense, Setaria italica, Echinochloa colonum and Paspalum sp. and reported that sorghum was the most preferred food plant. The delphacid vector P. maidis in the field was abundant in September to January and least in March to May and damp cloudy weather appeared most favourable for rapid increase.

Capoor et al. (1968) reported a serious disease of sorghum on cultivar, Maldandi in early 1960 affecting the rabi crop in Pune. The virus was found to be transmitted by Fulgorid, Peregrinus maidis (Ashmead) and its incidence varied from 6 to 70% in the kharif and 15 to 90% in the rabi season and designated it as "chlorosis of sorghum". Chatterjee and Nimbalker (1977) reported the incidence of maize stripe virus on maize ranging from 5 to 15% in different crop seasons at Pune. Disease symptoms appear as minute chlorotic spots gradually elongate and coalesce to form parallel stripes and vectored by P. maidis. Seth et al. (1972) reported streak disease, on bajra transmitted by a leafhopper, (Cicadulina mbila) which is not sap transmissible. It also

infects sorghum, maize, ragi, wheat, barley, oat, Panicum milia-
ceum, Setaria italica and S. verticilata but not sugarcane.

Moline (1973) reported three, mechanically transmissible viruses viz; wheat streak mosaic virus, maize dwarf mosaic virus and brome grass mosaic virus, were isolated and identified from corn and sorghum. A mosaic disease infecting maize, sorghum, johnsongrass and other grasses in Israel and transmitted both mechanically and by aphids. Mid summer temperature cause masking symptoms in infected plants of johnsongrass and maize but not in sorghum. Johnsongrass seems to serve as the virus reservoir in nature (Klein et al., 1973). Trujillo et al. (1974) noticed a new corn virus disease in Venezuela that produces partial stunting and white to yellow uninterrupted stripes which are narrow in early infected leaves and wider in the new leaves.

Tsai (1975) observed a disease on corn transmitted by corn planthopper (P. maidis) in Florida and not by sap inoculation. The virus disease induced chlorotic streaking between the veins and general chlorosis of new growth. A severe stunting of maize in Australia was noticed, which causes sterility and sometimes death of susceptible inbred lines. This disease was shown to be caused by rhabdovirus transmitted by delphacid planthopper, P. maidis (Greber, 1977). Agarwal et al. (1978) noticed that sorghum shootbug is a serious pest of sorghum due to introduction of new sorghum cultivars of different maturities. Similarly Nishida (1978) reported that the corn planthopper P. maidis was the key

pest of fodder maize in Kahuku. The seasonal incidence of delphacid P. maidis was studied during 1976 in Andhra Pradesh (Prabha-kar et al., 1986).

Anahosur et al. (1980) noticed during the general survey for sorghum diseases and pests in sorghum plant with symptoms of red stripe on leaves restricted to interveinal area. The plants appeared stunted and produced poor or no earheads. The presence of large population of aphids (Rhopalosiphon maidis) in infected plant transmitted similar disease when enclosed on young healthy sorghum seedlings. Greber (1981) and Migliori and Lastra (1980) noticed maize stripe virus disease commonly on maize and sweet corn in coastal Queensland, which was also affects wild sorghum, johnsongrass and sudangrass. Symptoms on maize leaves with discontinuous lines and yellow stripes were observed in Guadeloupe, West Indies. The disease also affected sorghum and Rottboeillia exaltata (wild grass) and it was transmitted in a persistent manner by P. maidis. The incidence of MStpV on maize from 40 to 50% was reported in Northern Queensland, Australia.

Gingery et al. (1979) reported a virus disease in Florida which is serologically related to maize stripe virus (MStpV) from East Africa. The MStpV isolate of Florida was transmitted in a persistent manner by P. maidis and produced similar symptoms as those reported from East African isolate. Nault et al. (1979) carried out survey of maize virus and mycoplasma like diseases in Peru and identified as maize stripe virus and maize mosaic virus transmitted by P. maidis.

Garud and Mali (1983) reported based on transmission, physical properties, host range and serological tests, the virus involved in sorghum red stripe in India was identified as sugarcane mosaic virus. In the International Sorghum virus nursery in Mexico maize dwarf mosaic virus (MDMV) was the most prevalent but sugarcane mosaic was found to be in association with MDMV as reported by Narros et al. (1983). Mote (1983) noticed unusual epidemic of P. maidis in Maharashtra, India in the winter sorghum during 1981-82. Due to increasing night temperature and low humidity between October to December the delphacid density increased ranging from 200-300/plant and drastically affected plant growth.

Greber (1985) observed maize stripe virus, transmitted by P. maidis affects maize and sweet corn in coastal and tropical districts of Australia. The virus has similar characteristics to MStpV in the USA and Africa. Its host range includes maize, sorghum, barley, rye and triticales. Rossel and Thottapilly (1985) demonstrated, with an isolate of maize stripe virus obtained at IITA (1975a), typical symptoms developed in sorghum cv. Rio, Rottboellia exaltata and maize following inoculation with infective P. maidis. Serological tests showed that the isolate is identical with maize stripe virus reported in USA, Kenya and Australia and it is also related to rice stripe virus from Japan. Gingery (1985) indicated that the virus occurs worldwide in most of the tropical maize growing regions where the distribution of

maize and Peregrinus maidis overlap. Klassen and Falk (1989) isolated small isometric virus particles from sudangrass causing sorghum yellow banding symptom in the Imperial valley of Australia. The virus was sap transmissible and found to infect narrow range of graminaceous hosts which include commercial sorghum and sorghum X sudangrass hybrid in Texas.

Ferreira et al. (1989) observed in sorghum experimental plots cvs. Atlas and Rio which exhibited chlorotic streaks and slight dwarfing. The disease was transmitted to other sorghum, maize and Rottboellia exaltata by P. maidis. This disease is not transmitted either by Dalbulus maidis nor Rhopalosiphon maidis and serologically reacted with antibodies of maize stripe tenuivirus. Pande and Alebejo (1990) conducted survey in Nigeria during 1990, indicated that maize mosaic virus was predominant virus in sorghum while maize stripe virus and potyvirus were also present in the sorghum land races. Peterschmitt et al. (1991) first reported a disease characterised by chlorotic stripes and bands on sorghum in Indian subcontinent with an incidence of 0.5 to nearly 10%. The disease could be transmitted by the delphacid planthopper P. maidis to sorghum but not to Zea mays or to any other cultivated and weed grasses. A virus disease caused by a tenuivirus and serologically related to maize stripe virus from Florida, Reunion and Venezuela and the virus infecting sorghum named as MStV-Sorg to distinguish from MStV which readily infect maize (Peterschmitt et al. 1991).

Singh and Rana (1992) studied the stability of resistance in sorghum to corn planthopper P. maidis over three plant growth stages in 56 sorghum germplasm accessions and found significant correlation between susceptibility and plant damage. Roca de Doyle et al. (1992) observed two virus isolates with maize stripe virus (MSV) and maize chlorotic syndromes (MCS) in Mauritius and considered the isolates as maize stripe virus. Both MSV and MCS induce different symptoms type and proposed that both are same and symptoms difference arised as a result of late and early infection, respectively.

2.4 Transmission

2.4.1 Insect transmission

The leafhoppers, planthoppers and their Auchenorrhyncha relatives were the first insects proven to be the vectors of plant viruses. In 1883 a Japanese rice grower transmitted the rice dwarf virus using the leafhopper Recelia dorsalis. The first report of planthopper transmission of a plant virus was 39 years later when Kunkel (1922) reported that P. maidis was the vector of maize mosaic virus. After 1930's reports documenting the role of leafhoppers and planthoppers as vectors of viruses and virus like pathogens increased substantially (Kisimoto, 1973; Nelson, 1985). Many aspects of virus transmission by hoppers were reviewed earlier by several workers (Chiykowski, 1981; Kisimoto, 1973; Maramorosch and Harris, 1979; Nault and Rodriguez, 1985; Purcell, 1982, Sinha, 1973, Nault and Ammar,

1989). Selected reviews concerning virus-vector i.e. SStV and P. maidis relationship are presented here under.

Shinkai (1962) found minimum acquisition access feeding time to be 15 min. by Laodelphax striatellus to acquire rice stripe virus and incubation period ranging from 5-10 days while in extreme case maximum acquisition period of 21 days was recorded. The insect became highly viruliferous in 1-2 weeks following the incubation period and the minimum inoculation feeding period time was 3 minutes. Females are found more efficient transmitters than males. McEven and Kawanishi (1967) reported that the corn planthoppers (P. maidis) can acquire the virus from infected corn in an acquisition feeding period as short as of 4 hours with latent period of 14-31 days and inoculation feeding period of 15 minutes. More transmission occurred during light hours than dark hours.

Sinha (1963) showed that the ability of Agallia constricta to acquire wound tumor virus depends on age at which insects were exposed to diseased plants. Transmission was found to be greater in nymphs than adults. The permeability of the gut wall of the insect to the virus presumably decreases with increasing age of the insect. Sogatodes oryzicola, vector of the rice hoja blanca virus has minimum acquisition access period of 15 min longer incubation period of 31 days and transmission period of 30 minutes (Galvez, 1968). Capoor et al. (1968) observed that even a single delphacid P. maidis is able to produce 78 per cent

infection of sorghum chlorosis whereas group of five or more were able to produce 100 per cent infection. The minimum AAP of 1 hour and inoculation feeding period of 15 minutes was observed in transmission studies. A single viruliferous insect could retain and transmit the virus upto 45 days when serial transfers were done each day. The results also indicated that virus multiplies in the vector and retains the virus for life having acquired once.

Ammar (1975) showed that ten planthopper Javesella pellucida transmitted European wheat striate mosaic (EWSM) from diseased plants with an average efficiency of 31 per cent when compared to 10 per cent by J. dubia. Reddy and Black (1972) reported that with one day acquisition period by leafhopper (Agallia constricta) to wound tumor virus concentration increased 50 to 100,000 fold between 8 and 25 days after acquisition. Seth et al. (1972) reported a streak disease of bajra transmitted by a jassid vector Cicadulina mbila wherein a single nymph or adult can transmit the virus after 15-30 min AAP. The minimum incubation period of the virus in vector was about 3 days and 5 to 7 days in plant. Kulkarni (1973) demonstrated the transmission of maize stripe virus using P. maidis and found minimum acquisition period of 5 days followed by a test feed of 6 days. He also provided evidence to show that nymphs were possibly more efficient than adult as vectors.

Sylvester et al. (1974) reported that strawberry crinkle virus was maintained through 6 consecutive serial passages in

the vector Chaetosiphon jacobii. The rate of successful inoculation upto 90 per cent and a stable incubation period indicated that the virus titer was being maintained by multiplication in the aphid. Tsai (1975) showed that a corn disease transmitted by P. maidis in Florida has a minimum incubation period of 4 to 6 days in younger plants and 30 to 45 days in older plants. The per cent infection decreased and the incubation period increased with the increase in age of the host plant. Lastra and Esparza (1976) reported the maize mosaic virus (MMV), a plant rhabdovirus multiplied in the vector (P. maidis) and reached the titer of 10^6 per insect in 5 to 10 days after acquisition. Hibino et al. (1979) studied two kinds of tungro associated viruses transmitted together or separately by Nephotettix virescens from rice infected plant by both the viruses. The virus was acquired by vector in 30 minutes AAP, transmitted in 10 minutes IAP and retained by the vector for 3 days.

Migliori and Lastra (1980) noticed a virus like disease on maize and sorghum in Guadeloupe, French West Indies and transmitted in a persistent manner by P. maidis (Ashm). The incubation period in the vector was 18-25 days. The virus proved positive against an antisera of an isolate of maize stripe virus from Florida. Conti (1980) observed that planthopper Laodelphax striatellus was an experimental vector of barley yellow striate mosaic virus (BYSMV). It was found that the minimum AAP by the vector L. striatellus for transmission was found to be one hour,

inoculation feeding period of 15 minutes and a latent period of 15-16 days and retained the infectivity upto 36 days. Autrey (1980) showed that nymphs of P. maidis appeared to be more efficient than adults in transmitting maize mosaic virus. The virus was acquired in less than 15 minutes with a latent period of 9 days and virus could be transmitted with feeding period of 15 minutes. The latent period of virus in the host varied with growth stage ranging from 10-20 days after emergence.

Nault et al. (1980) demonstrated that in maize the rate of maize rayado fino virus ^{transmission} by a single planthopper Dalbulus maidis was 15 per cent with a mean latent period of 16 days. Whereas the rate of transmission of 77 per cent was observed when leafhopper injected with 10 ug of partially purified virus with a mean latent period of 6-9 days. The nymphs acquired and transmitted the virus more efficiently (13.5%) than adults (3.5%) and transmission efficiency was almost similar in both male and females.

Nagaraju and Viswanath (1981) found that minimum AAP of 6 hours by leafhopper Cicadulina chinai (Ghauri) for transmitting ragi streak virus, one hour to become viruliferous and then vector remained infective throughout its life period. The minimum inoculation feeding period was 30 minutes and a single leafhopper was efficient (80%) in transmitting the virus. The incubation period of virus in the host was 6 days. Greber (1981) observed that the incubation period of 10 days in P. maidis and it transmitted the maize stripe virus up to 22 days. The minimum

AAP was found to be less than 4 hours and transmission feeding period was one hour and 24 per cent of insect populations transmitted the virus after 48 hour of acquisition period. Similarly Greber, (1982) showed that maize mosaic virus was transmitted by P. maidis with an incubation period of 10-14 days in vector after acquisition and transmission was found upto 23 days or until the death of insect.

Varon et al. (1982) reported that a rhabdovirus was transmitted in a persistent manner by P. maidis. He also found that AAP was of 48 to 72 hours and incubation period of 4 to 22 days were seen in the vector and in susceptible young plants the average incubation period was 12 days. Tsai and Zitter (1982) studied the relationship between maize stripe virus and its vector P. maidis. The virus is transmitted in a persistent manner. The second and third instar nymphs transmitted the virus with twice the efficiency after 24, 48, 96 and 192 hours AAP as did adults. Macropterous adults were slightly more efficient in transmission than brachypterous adults. The minimum AAP of virus by second and third instar was 4 hour and incubation period, and in adults is of 4 to 5 days. The average retention of MStpV by second and third instar was 13.7, 13.2 and 15.8 days after 48, 72 and 96 hours AAP whereas in adults it was 3.7, 5.5 and 6.5 days, respectively.

Chaudhury and Rosenkranz (1983) observed that the rate of transmission of maize chlorotic dwarf virus (MCDV) by an adult

Graminella nigrifrons was 34-35 per cent. The rate of transmission was found to be more by females (46%) than by males (29%). The transmission rate of MCDV by the vector G. nigrifrons was higher in their fourth week as adults with a life time transmission rate of 86%, females were better vectors and survived longer than males as reported by Knoke et al. (1983). Zhou and Rochow (1984) compared 5 stages of Schizaphis graminum as vectors of SGV isolates of barley yellow dwarf virus and found that adults are more likely to transmit efficiently if they had acquired the virus as nymphs. The incremental pattern of virus transmission differences among the five stages suggested that the S. graminum could be useful for basic studies of virus-vector interactions.

Mathew and Basu (1986) observed that the grassy stunt virus of rice in Philippines is transmitted by brown planthopper Nilaparvata lugens. The minimum AAP of virus by the vector was 30 minutes and maximum was 72 hours. The incubation period ranged from 5 to 15 days during April to September and 18-30 days during November to January. The incubation period on plant ranged from, 9-35 days (April to September) and 43 to 95 days (November to January). The results showed that the overall per cent of infective individuals were 66.6, 57, 62.5 and 60 in macropterous female and male and brachypterous female and male respectively. Macropterous female is likely to play crucial role in field spread and epidemiology. Nault and Gordon (1988) demonstrated the multiplication of MStpV using ELISA in delphacid vector P. maidis. MStpV was detected by ELISA from single planthopper 2

days after AAP and detected in increasing number of insects at 9, 16 and 23 days after AAP.

Ammar et al. (1987) reported that P. maidis reduced significantly the fraction of insect transmitting maize stripe virus when they exposed maize to maize mosaic virus. In contrast access to MStpV infected plants had no effect on the acquisition and transmission of maize mosaic virus by the vector P. maidis. The maize yellow stripe virus (MYSV) is transmitted in a persistent manner by the leafhopper Cicadulina chinai (Ammar et al., 1989). It was also found that the minimum AAP is 30 minutes, latent period ranged from 4.5 to 8 days, and retention period as long as 27 days. Greber (1989) demonstrated the serial transmission of chlorosis striate mosaic virus (CSMV) by single insect Nesoclutha pallida. He recorded a minimum latent period of 12-14 hour and regular transmission with occasional breaks upto 50 days. The rate of transmission of CSMV with chlorosis biotype of N. pallida and paspalum striate mosaic virus (PSMV) reached 50 per cent with single insect only when freshly infected source plants were used.

2.4.2 Transovarial transmission

Many of the leafhopper and planthopper transmitted viruses could not be transmitted to another plant by the vector until after a latent period of days or weeks after the start of the acquisition feeding. Multiplication of the virus in the vector

one of the possible explanations of the long incubation period (Brakke, 1988). Black (1953) reported that females of Agalliopsis novella reared on crimson clover plants infected with wound tumor virus oviposited eggs which produced 1.8% of infective progeny. Evidence was showed that the higher rate of transovarial passage of this virus through eggs. Showers and Everett (1967) experiments showed that progeny of rice delphacid Sogatodes oryzaicola and its reciprocal crosses of rice hoja blanca virus (RHBV) transmitting males to nontransmitting females or vice versa transmitted RHBV to healthy seedlings without having fed on diseased plants.

Galvez (1968) reported a high percentage of transovarial transmission of rice hoja blanca virus with an acquisition access period of 15 min and a long incubation period (31 days) of virus in the insect. Sylvester and Richardson (1969) reported one percent transovarial passage of the sowthistle yellow vein virus to larvae of the aphid vector Hyperomyzus lactucae. Ammar (1975) observed the transovarial transmission of European wheat striate mosaic virus (EWSMV) ranging from 6 to 43.1% of the progenies of infective females of Javesella pellucida planthopper. Gingery et al. (1981) reported that the maize stripe virus (MStpV) was transovarially transmitted by its vector P maidis. Forty six of seventy nine (58.21%) nymphs from eight viruliferous females transmitted MStpV establishing transovarial passage of virus from adults to progeny. The maize stripe virus is persistently transmitted by its only known vector the delphacid planthopper P maidis.

Raga et al. (1988) demonstrated that temperature had a marked effect on the role of transovarial passage of rice stripe tenuivirus in its planthopper Laodelphax striatellus. At 17.5°C 83% of viruliferous females passed virus to their progeny when compared to 12.5% at 32.5°C. Tsai and Zitter (1982) have demonstrated that maize stripe virus could be transmitted by haemolymph injection and transovarial passages. Their studies also suggested that out of 78 nymphs 8 individuals (10.3%) transmitted MStpV and in another test 6 per cent of 86 individuals transmitted the virus. Insects continuously reared on MStpV infected plants found to have higher rate of transovarial transmission.

Shinkai (1962) proved that the virus could pass through the eggs to a very high percentage of the progeny for 23 consecutive generations in Laodelphax striatellus which transmit rice stripe virus. Conti (1980) reported that two out of five infective females of L. striatellus transmitted barley yellow striate mosaic virus (BYSMV) transovarially and the larvae became infective in the second week after hatching and transmitted upto three weeks.

2.4.3 Seed transmission

Hamilton (1965) developed rapid and accurate serodiagnostic procedure for barley stripe mosaic virus in individual barley embryos and found the method more reliable and useful in the large scale screening of commercial seed lots of barley and other

cereal crops. Slykhuis (1967) reported that barley stripe mosaic virus (BSMV) is the only definite seed borne virus known to infect graminaceous plant. Its perpetuation in barley and wheat depends on seed transmission. The distribution and incidence of BSMV in barley and wheat is directly related to seed transmission and supplemented by contact and pollen transmission. It provides source of virus that can spread by various means. The greenhouse and field results indicated that no seed transmission of barley stripe mosaic occurred in plants inoculated 7 days prior to anthesis. More plants were infected with virus from ovules than from pollen of barley plants (Timian, 1967).

Hill et al. (1974) reported low percentage of seed transmitted wheat streak mosaic and 0.2% for maize dwarf mosaic virus. Results of mechanical inoculation of several maize inbred lines showed that both viruses could be recovered from symptomless plants. Tomlinson and Walker (1973) showed that when seeds of chickweed (Stellaria media) even after burying for 12 months contained cucumber mosaic virus (CMV) and produced 5 per cent infected seedlings. Even though in several weed species the virus was detected in the seeds, it was not transmitted to any of their seedlings. Handa and Harrison (1977) also reported transmission of nepovirus through chick weed seed. The seedlings of these were symptomless at 15-25°C and expressed symptom on third or fourth week after inoculation at 33-37°C.

Carroll (1972) noticed that barley stripe mosaic virus strain T in pollen, embryo and endosperm of seed but transmission

did not occur. Transmission did occur through seed when virus occurred in pericarp embryos, ovules and pollen and it passed from the embryos to the seedlings during germination. Autrey (1980) attempted seed transmission of maize mosaic virus using earheads collected in the field from early, midway and late in the growth cycle. Out of 12,683 seeds sown no plant was found with symptoms of the disease. Similar results were obtained with barley yellow striate mosaic virus (BYSMV) which was transmitted through wheat seed nor did it infect hosts of other rhabdovirus (Conti, 1980).

Pinner et al. (1988) showed that several hundreds of plants propagated from seed collected from originally infected plant grew without symptoms. This confirmed that the maize streak is not seed transmissible. Cicadulina leafhoppers failed to transmit any virus to maize from these plants. Caldwell (1962) explained the lack of seed transmission in large number of plant viruses due to sterility, absence of virus in embryos, breakdown of plasmadesmata between tissues of endoplasmic and embryonic tissues and devastating effects on the prophase meiosis.

2.5 Host range

2.5.1 Host range of virus

Gorter (1947) reported maize streak virus symptoms on maize, wheat, oats, barley, rye, finger millet, pearl millet, sorghum,

sugarcane and napier fodder (Pennisetum purpureum). Oswald and Huston (1953) observed that out of 55 grasses tested for cereal yellow dwarf virus 36 species proved to be hosts. Twenty species exhibited typical cereal yellow dwarf virus symptoms, sixteen species showed no symptom but proved to be capable of carrying the virus continuously. Winter weather favoured the growth of grasses and reproduction of vectors.

Galvez *et al.* (1961) transmitted the rice hoja blanca virus to Echinochloa colonum (L.) Link, Leptochloa sp., Digitaria sp., Triticum aestivum, Hordeum vulgare and Avena sativa but not to maize or sorghum using planthopper Sogata cubana. Capoor *et al.* (1968) successfully transmitted the virus to Canna orientalis, Cynodon dactylon, Dicanthium annulatum, Dinerbra retroflexa, Euchlena mexicana, Pennisetum typhoides, Saccharum officinarum and Zea mays. He also reported several grass species in nature as host for sorghum chlorosis virus transmitted by P maidis.

Roane and Tolin (1969) reported five perennial grass species as new hosts of maize dwarf mosaic virus (MDMV). The epidemic proportions of the virus disease occur only if Sorghum halepense is present and infected with MDMV. Mosaic virus isolates infecting corn, johnsongrass, sweet sorghum were serologically related based on their relation with MDMV strain A (Zummo and Gordon, 1971). Seth *et al.* (1972) demonstrated that maize streak virus on wheat was also transmitted to maize, bajra, sorghum and many wheat varieties. It has been identified based on host range and

vector Cicadulina mbila as Pennisetum strain of maize streak virus. The streak disease of bajra transmitted by C. mbila also infect bajra, maize, sorghum, ragi, wheat, barley, oat, Panicum mileaceum, Setaria italica and S. verticillata but not sugarcane.

Kulkarni (1973) reported that species susceptible to maize stripe virus are barley, sorghum, oat, rice and sugarcane whereas molasses grass remained symptomless. Watson and Gibbs (1974) correlated host range data of certain viruses with taxonomic grouping of grasses and the results showed that barley yellow dwarf virus and cock foot phloem mottle virus infected greater proportion of the festucoid grasses than nonfestucoids. Nagaraju et al. (1982) reported that ragi streak virus transmitted through a leafhopper Cicadulina chinai (Ghauri), on artificial inoculation it infected several graminaceous hosts composed of economic crops, fodder grass and weeds. A rhabdovirus causes severe stunting and sterility of susceptible maize genotypes in Australia. Maize sterile stunt also infects Aegilops variabilis, barley (Hordeum vulgare), barnyard grass and wheat. The natural vector of the virus Sogatella longifurcifera, a delphacid, was commonly found on maize and Echinochloa colona (Greber, 1982).

Autrey (1980) showed that among the tropical and temperate grasses only Sorghum verticilliflorum, Rottboellia exaltata spring barley became infected with maize mosaic virus. Conti (1980) demonstrated that out of 44 species of gramineae inoculated with barley yellow striate mosaic (BYSMV) by its planthopper vector

Laodelphax striatellus 26 in eight tribes were infected. It also infected barley, Bromus sp., oats, Setaria italica and Sorghum spp.

Greber (1981) reported that maize stripe virus was transmitted by P. maidis which affect maize and sweet corn in coastal and tropical districts of Australia. The host range includes Zea mays, sorghum, barley, rye, triticales wild sorghum (Sorghum sudanense), Johnsongrass (S. halepense) and S. sudanense X S. bicolor hybrids. Sharma and Payak (1983) reported that planthopper P. maidis is the experimental vector of maize stripe virus. The MStpV infected other hosts like Avena sativa, Bracharia mutica (Forsk.) Stapf, Echinochloa pyramidalis (Lam.), E. crusgalli (L.) Beauv., Hordeum vulgare (L.), Panicum antitotale Retz., Panicum maximum, Pennisetum americanum (L.) Beauv, P. purpureum Schumach, rice, Setaria italica (L.), Beauv, sorghum, sugarcane and wheat on artificial inoculation. The rhabdovirus causing maize mosaic in Shiraz, Iran was transmitted by Ribautodelphax notabilis, which also transmitted the virus to wheat, barley and other graminaceous host plants. (Izadpanah et al., 1983).

Ammar et al. (1989) showed that maize yellow stripe virus (MYSV) associated with tenuivirus was transmitted in a persistent manner by the leafhopper Cicadulina chinai from maize to maize, wheat, barley and then wheat to maize plants.

2.5.1 Host range of planthoppers

McClellan (1947) showed that annual grasses such as Eleusine indica often support Cicadulina populations which is a vector of maize streak virus on maize. Lamey et al. (1964) indicated that leafhopper Sogatodes oryzicola, vector of hoja blanca virus of rice survived well on rice, wheat and domestic grasses. Completion of its life cycle occurred readily on rice and Oryza perennis but not on other species.

Yoshimeki (1966) reported that viruliferous Laodelphax striatellus overwintered on wheat and barley. The adults migrate to the rice field when the population densities became high, the macropterous form increased. In later generations they acquire the virus by feeding on infected plants. Chellaiah and Basheer (1966) found that P maidis planthopper attack sorghum, Zea mays and Pennisetum typhoides Stapf. and Hubbardot in South India. Besides these hosts, Sorghum halepense, Setaria italica Beauv, Echinochloa colona var. frumentacea and Paspalum scrobiculatum Linn., Sorghum halepense appeared to be the most favourable host when compared to the other hosts.

Pitre and Hepner (1967) collected 36 species of leafhoppers from corn, winter grasses, oats, rye grass, wheat and bahia grasses. Graminella nigrifrons and Macrosteles fascifrons accounted for 36% and 12.5% leafhopper population respectively. The population reached peak in May, June and declined in July and increased again on August and September. Rose (1974) listed

extensive cereal and grass hosts of three species of *Cicadulina* and each have been found on cereal crops annual grass and common weeds in cultivated lands in Africa.

Berger (1980) reported that greenbug *Schizaphis graminella* Rondai, a vector of maize dwarf mosaic virus (MDMV-A) has short cycles recurring from infected sorghum back to maize, sorghum, johnsongrass and annual grasses. Damsteegt (1983) reported several grass species in the genera *Aegilops*, *Andropogon*, *Avena*, *Bothrichloa digitaria*, *Echinochloa*, *Eleusine*, *Hypertheria*, *Panicum*, *Schizachrium*, *Sorghastrum*, *Sorghum*, *Trichachne*, *Trichloris* and *Zea* which supported abundantly for oviposition and nymphal development of vector *Cicadulina mbila*. *Graminella nigrifrons* survived better on small grains and grasses than in maize in the field. The highest populations of the maize dwarf mosaic virus (MDMV) vector were recorded on *Echinochloa crusgalli*, *Digitaria sanguinalis* and *Cynodon dactylon* (Knoke *et al.* 1983). Hunt and Nault (1990) showed that annual grasses may be superior to perennials as hosts for leafhoppers *Graminella nigrifrons* (Homoptera : Cicadellidae). The young maize is most suitable for leafhoppers.

2.6 Epidemiology

The intensive agriculture involves a complex of overlapping of growing seasons and crops with a diversity of weeds and crop species. The important problem in virus epidemiology is to

identify the vector sources and to assess their relative importance in field transmission. The disease incidence is a function of various aspects of host, vector, its source, environment and time and interactions will influence the incidence, distribution and spread of the virus disease in the field. Various aspects of epidemiology of cereal viruses are reviewed by Plumb and Thresh (1983), Maramorosch (1969), McClean et al. (1986) and Kiritani (1983).

Storey (1936) believed that the major source of maize streak disease was the previously planted cereal crops and grasses around the field. In warmer regions a succession of planting of irrigated maize is a common cause for increased streak infection (Gorter, 1953, Herd, 1956). McClean (1947) found that annual grasses Eleusine indica with mild maize streak virus symptom are widespread and they often support Cicadulina populations for the spread of maize streak viruses. Perennial grasses cultivated as pastures, if irrigated often supported dense populations of Cicadulina spp (Ruppel, 1965).

Sutic and Tasic (1966) and Paliwal et al. (1968) reported that Sorghum halepense serves as a perennial host of maize mosaic virus in Yugoslavia and in India respectively and can overwinter on graminaceous weed Setaria italica and Eleusine indica. Volunteer plants developing from stubbles of cultivated sorghum are served as source of inoculum. The seed transmission of maize mosaic virus plays an important role in distribution and carry over from season to season. The pattern of spread of MMV during

the growing season is influenced by the presence of Sorghum halepense as a primary source of infection and later spread by the active vectors in the field (Tosic and Sutic 1977).

Wallace and Murphy (1938) showed vast acreages of wild host served as reservoirs of viruliferous leafhoppers and maintenance of virus throughout summer and fall in Southern Idaho. Amano (1937), Shinkai (1956), Yamada and Yamamoto (1956) and Sugiyama (1966) indicated that many members of the gramineae (34 species) are hosts of rice stripe virus which showed mild symptoms with chlorotic streak or mosaic mottling. Setaria italica, S. viridis, Digitaria adscendens, D. violascens and Ergrostis multiflorum are frequently infected in the field. Lamey et al. (1964) reported that Sogatodes oryzicola (Muir.,) a vector of rice hoja blanca virus survived well on bluebonnet 50, rye, triumph wheat and domestic rye grasses and served as source of inoculum.

Bradbert (1957), Hurst (1965) and Watson (1966) reviewed that increased survival of crop, weed hosts, vectors in mild winter and protected sites play an important role in spread of viruses early in the main growing season. Duffus (1971) and Mathews (1971) reviewed that the rate at which virus spreads between plants varied according to the type of virus, crop environment and mode of transmission. Viruses spread both from outside and within crops and newly infected plants soon became foci for secondary spread. They also reviewed the role of weeds in the incidence of virus diseases which act as reservoirs for

both virus and vector and perpetuation from season to season. Many viruses thought as pathogens of wild plants, play an important role in spreading in crops introduced in near by vicinity. The increasing use of irrigation to obtain crops during dry season is likely to increase the incidence of diseases as reported in rice and maize (Bakker, 1970 and Rose, 1972).

Bock (1974) suggested that some strains of maize streak virus were adapted to wild hosts, and later proved highly pathogenic to exotic maize when it was introduced in Africa. Dinoor (1974) reviewed the role of wild and cultivated plants on the epidemiology of plant diseases which served as reservoirs and constantly serve as sources of inoculum to many diseases. Knoke et al. (1974) showed that maize dwarf mosaic virus (MDMV) was most prevalent in Ohio from mid July to September in presence of infected plants. The increased in aphid populations during these months resulted in corresponding increase in field transmission of MDMV. Tomic and Sutic (1977) indicated that Sorghum halepense served as a perennial host for maize mosaic virus in the fields of Yugoslavia. The transmission of virus through seed allows rapid spread in field. Similarly the presence of S. halepense as a primary source of inoculum and secondary spread by active vectors. Lastra (1977) reported that Rotteboellia exaltata served as an alternate host for P. maidis for transmission of maize stripe virus and maize mosaic virus in Venezuela.

Nault et al. (1980) showed that out of 48 graminaceous species in 25 genera tested only Zea mays and its teosinte sub species and hybrids were susceptible to maize rayado fino virus (MRFV). The tropical weed Rottebellia exaltata could serve as an overwintering host for MRFV. Maize dwarf mosaic virus (MDMV) disease was vectored by 23 species of aphids (Knoke and Louie, 1981). These vectors interacted with several ecological factors to produce MDMV epidemics in sorghum. Johnsongrass the perennial reservoir of MDMV strains plays a central role in the disease cycle. The greenbug (Schizaphis graminum) overwintered on small grains and winter grasses (Toler, 1980).

Greber (1981) listed several natural wild hosts for maize stripe virus which include wild sorghum (Sorghum verticilliflorum), S. halepense, S. sudanense, barley rye and wheat where as P. maidis vector of maize stripe virus survived well in moist climate and less in dry. Knoke and Louie (1981) found the survival of MDMV-A between growing seasons in Sorghum halepense which acts as reservoir for the virus. Fargette et al. (1982) showed that there is a large reservoir of barley yellow dwarf virus in perennial grasses in addition to winter wheat, spring oats and corn in Indiana. Thresh (1982) and Thresh (1974) reviewed the epidemics of plant viruses transmitted by vectors and said severity is related to the interactions between vector population, availability of alternate hosts for both virus and vector, the distribution proximity and environmental factors. In tropics, where the vectors breed continuously and spread between succession of rainfed and irrigated crops or from grass and

weeds. The transovarial transmission is so frequent in leafhoppers, that a virus can persist through many generations. The maize streak virus infection was found 100 per cent in maize planting in the warm season at Mauritius while in dry cool season, the infection was less than 5 per cent (Anon., 1975).

Rose (1974) reported that the rates of spread of maize streak incidence was increased when infected plants colonized by Cicadulina spp. were removed resulting in the disturbance of the vectors. Large populations of insects (1 leafhopper/3 plants) resulted in an exponential increase in the incidence of maize streak infection. Rose (1974) listed several cereal and grass hosts of three species of Cicadulina whose the populations have been found on major cereal crops and annual grass weeds which are common in cultivated lands of Africa. Maize streak vectors dominated by adaptations for their survival seasonally and by planting irrigated wheat and other cereal crops in dry seasons helped in breeding of cicadulina populations and also serve as centres for multiplication of virus (Rose, 1978).

Mangelsdorf (1974) reported that Rotteboellia exaltata, an annual weed related to maize may be an important alternate host for maize rayado fino virus (MRFV) because it flowers and produces viable seed throughout the year. Tripsacum australe reported to be a potential overseasoning host for MRFV which is wide spread in South America. Penrose (1974) isolated sugarcane mosaic virus from 27 native and introduced grass

species and found that johnsongrass served as principal reservoir of SCMV.

Converse et al., (1979) observed that the spread of aphid borne yellow edge virus occurred in the field at random with in the field plots. the number of infected plants adjoining other infected plants were compared with the total number of infected plants/plot and predicted the pattern of disease spread in the field. Graham (1979) reported that Cicadulina mbila, vector of maize streak virus restricted to tropics and subtropics but not found in United States. The inability of the domestic insect to transmit maize streak virus reduce the threat of disease in corn production.

Kiritani (1979) reported that the essential requirements for epidemics of rice tungro virus to spread are, abundance of virus sources, the presence of susceptible hosts, adequate population density of planthopper vectors, and environmental factor including cropping systems. Autrey (1980) reported that the population of P. maidis was found to be higher in the warm season than in the cool, the increased population of vectors coupled with continuous cropping are the main factors responsible for the high incidence of disease in maize. The spread of maize streak was rapid in early vegetative period whereas in case of maize mosaic virus, maximum spread occurred in the middle of vegetative period.

Autrey and Ricaud (1983) review the factors affecting the incidence, spread and carryover of virus and vector populations. The annual weeds and grasses which grow throughout the year harbour maize streak virus and bridge the gap between two successive maize crops. The build up of disease and leafhoppers was slow in main crop but when the second crop follows in the immediate vicinity, the disease build up is exponential resulting in 100 per cent infection. Greber (1982) reported that weekly rating of the incidence of maize sterile stunt virus disease showed a peak symptom development in susceptible maize 6 weeks after emergence during mid summer 1980, very few or no colonization of P. maidis were observed during the main infection period. Madden and Nault (1983) observed that the differential pathogenicity of Corn stunt virus to vector Dalbulus maidis, can be rationalized according to the geographic distribution and host ranges of leafhoppers and pathogens.

Rose (1978) observed that changing agricultural practices has been responsible for the importance of maize streak disease in Africa and India. Maize streak vectors are dominated by adaptations that evolved for survival of cicadulina populations in seasonally green grasses. Irrigated wheat and cereal crops in dry season may favour the survival of Cicadulina vectors and also multiplication of the viruses. Madden et al. (1982) indicated that the randomness of the maize dwarf mosaic virus infected plants in the field ranged from 100 per cent at the highest incidence to zero per cent at the lowest incidence.

Trujillo et al. (1978) observed that two field populations of P. maidis taken from raya fino virus infected maize 12 and 21 per cent of the individuals transmitted the disease, only 8 per cent of a population reared in the laboratory were able to transmit the virus. Gibbs (1983) described the value and simplicity of the convulsion method for describing and comparing the distribution pattern of virus affected plants in the field. The distribution of virus infected individuals can provide useful clues to the sources and mode of spread of the virus.

Tosic (1983) reported that johnsongrass (Sorghum halepense) served as overwintering host for maize mosaic virus-YV in addition to maize and sorghum. Maize dwarf mosaic virus was introduced into main maize plots from virus infected johnsongrass (S. halepense) and overwintering graminaceous grasses as reported by Knoke et al. (1983) and Zhu et al., (1983).

Ofori and Francki (1985) demonstrated that leafhopper A virus (LAV) multiplied and transmitted vertically through eggs of Cicadulina bimaculata and horizontally in insects feeding on plants in which it circulates transiently. Thus maize plant acts as reservoir of LAV and the plant is looked upon as a circulative but non-persistent vector of an insect virus. The first and second generation of Laodelphax striatellus are infective from the transovarial passage of the rice stripe virus. The later generation insects acquire the virus by feeding on the infected plants. The first generation overwintered on wheat, barley and graminaceous weeds (Ou, 1985).

Ling et al. (1983) demonstrated that the proportion of infected plants in an area has an important influence on the virus spread. The tungro virus infected rice stubbles remaining from previous crops is the main source of virus and vectors. Autrey and Ricaud (1983) reported that intensive maize cultivation and sequence of planting over a longer period resulted in the severe epidemics of maize streak disease in Mauritius. Rodrigo Gamez (1983) reported that grasses susceptible to maize rayado fino virus (MRFV) and the typical overlapping sequence of crops during the rainy season allows continuous breeding of Dalbulus maidis and the rapid spread of MRFV. Rosenberg and Magor (1983) related the spread of vector borne plant virus on their mobility and dispersal of plant viruses transmitted brown planthopper Nilaparvata lugens.

Duffus (1983) discussed that the severity of curly top attack of beet depends on the climatic factors, the weed hosts of the virus, the prevalence and severity of the virus, reproductive capacity and strain of the leafhopper. Ou (1985) reported that in field population of Sogatodes oryzicola a vector of rice hoja blanca virus the proportion of the active individuals was 7 to 12 per cent transmitting the virus. Klein et al. (1973) reported in Israel that johnsongrass seems to serve as the virus reservoir of mosaic disease affecting maize, sorghum and kharif corn in nature. Gildow and Arcy (1988) showed the role of small grains barley and oats as reservoir of barley yellow dwarf virus and aphid vectors. Ammar et al. (1989) suggested that wheat, barley

and possibly graminaceous weeds may serve as winter hosts or reservoir of maize yellow stripe virus (MYSV) and its leafhopper vector (Cicadulina chinai) in Egypt. Similarly the infested grasses and volunteer wheat and maize served as winter virus reservoirs of barley yellow dwarf virus.

Louie and Knoke (1991) reported that susceptible maize plantings, grass weeds, natural distribution of johnsongrass act as overwintering hosts of maize dwarf mosaic virus-A. Similarly, the young seedlings or rhizomes of Eleusine indica, Echinochloa crusgalli, E. glabrescens, E. colona, Leersia hexandra, Panicum repens and Cyperus rotundus infected with rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) serve as source of inoculum and later spread by potential vector Nephotettix nigropictus in weed and fallow fields (Khan et al., 1991). Garud et al., (1991) reported that the percentage of sorghum plants infected by sorghum red stripe virus increased with decreasing proximity to sugarcane field. Grain yield was negatively correlated with the number of leaves affected. Kondaiah and John (1977) reported that tungro virus can be recovered from infected leaf pieces dried for several days. Although healthy rice plants are the most preferred as host by the vector Nephotettix virescens, accidental feeding on infected debris will cause infection to rice plants. In vitro isolation of the rice tungro virus can be recovered from detached infected leaves after 15 days as reported by Kondaiah et al. (1976).

Prasad Rao and John (1974) observed the rice tungro virus in rice stubbles during off season. The vector of the virus Nephotettix virescens prefers to feed on rice plant but in absence of rice it thrives well on weeds like Paspalum disticum, Echinochloa colonum, Cyperus rotundus and Cynodon dactylon in the order cited. Thresh (1988b) indicated that it will be worthwhile to attempt to eliminate the source of infection in the field and it can only be decided on the basis of detailed knowledge of such sources and the ways in which the virus spreads from them into the main crop.

Madden et al. (1986) assessed the maize dwarf mosaic virus infected plants at 8 successive weeks in trap plants and found that the disease incidence varied with distance and source of inoculum. Number and species composition of aphids also varied with time and few species of aphids were related to high disease incidence. Nault and Madden (1985) working on the development of Dalbulus species from egg to adult on maize and perennial grasses found that development was significantly faster on maize (29 days) than on Tripsacum dactyloides (34 days). The results suggest that herbivorous insects on annual grasses have shorter generation time and low fecundity than on perennial species. Madden et al. (1990) reported that maize chlorosis dwarf virus (MCDV) spread can be substantial when viruliferous Graminella nigrifrons leafhoppers are introduced on to a field of susceptible maize.

2.7 SSTV on plant growth and yield

Jennings (1963) reported rough estimates of grain yield upto 25% loss in the cuban rice and more than 50% in Venezuela in 1956 due to rice hoja blanca virus indicating the potential seriousness of the disease. Each unit of increase in virus disease index appears to reduce yield by 10 per cent. Lamey et al. (1965) showed that age of plant affects susceptibility to hoja blanca virus. The susceptible cultivar Blue bonnet 50 inoculated at 1, 2 and 3 leaf stages developed 83, 67 and 65 per cent diseased plants respectively, whereas moderately resistant cultivar Arkrose developed 64, 16 and 0 per cent infection. Many of the field resistant cultivars were susceptible when inoculated at one leaf stage.

Catherall and Griffins (1966) reported that in cocksfoot streak mosaic virus infected plant, the tillering was decreased by about 40 per cent and dry matter was decreased by 10 per cent. The result also indicated that infected plant flowered earlier and produced fewer slightly smaller viable seeds when compared to healthy plants. The Irish perennial rye grass infected with barley yellow virus was stunted and caused greater loss of yield of herbage.

Paliwal et al. (1968) observed that maize plant infected with maize mosaic virus delayed flowering by 5 days, reduced plant height by about 50%, ear and plant weight by about 74% and dry matter content by 36 to 57%. Scheifele (1969) pointed out

that the time of infection of maize by maize dwarf mosaic virus is extremely important that early infected plants showed reduction of yield upto 36% compared to 19 per cent yield loss in late infected plants. Batte et al. (1970) reported that maize dwarf mosaic virus strain-A on maize caused delayed maturity stunting, lowering test seed weight, reduction in head size and 1000 grain weight. The results also indicated that MDMV had little or no effect when inoculated after 40 to 47 days of growth. The yield of sorghum and sudangrass hybrid was reduced for the second and third cuttings but not in the first due to infection of maize dwarf mosaic virus. There was no detrimental effect of the virus on protein content and digestability of either grass (Canerday and Guruskas, 1970).

Doodson and Saunders (1970) found that severely affected plants of wheat, oat, barley by barley yellow dwarf virus were stunted in growth and grain yield was considerably reduced. Rosenkranz and Scott (1978) showed that when corn plants inoculated with maize dwarf mosaic virus strain-A at 3, 5, 9 and 11 leaf stages, the highest disease incidence (58%) and the greatest yield reduction (23%) were obtained when inoculated at 5 leaf stage. MDMV-A under favourable conditions for disease development has the potential for reducing grain yield as much as 45 to 79 per cent in grain yield of maize (Giorda and Toler, 1985).

Guthrie (1978) showed, that there was strong correlation between the time of infection and yield loss in maize infected

with maize streak disease, under field condition the yield reduction ranged from 25 to 60 per cent. Garud and Mali (1980) revealed highly significant reduction in yield in sorghum due to red stripe virus disease at 20 days after emergence of seedlings. However, the virus affected plant height, cob length and grain yield per cob at all stages of inoculation. Reduction in grain yield of sorghum upto 67% in rabi and 53% in kharif due to sorghum red stripe virus was also reported (Vyavahare et al., 1989). Significant reduction in plant height, number of leaves, leaf area, stem girth and 60% reduction in grain yield due to sorghum red stripe virus was observed in 5 sorghum genotypes inoculated at 4th leaf stage (Choudekar et al., 1989). Pawar et al. (1990) demonstrated reduction of plant height, leaf area and chlorophyll content of sorghum cultivar at all growth stages of infection by red stripe virus.

Gregory and Ayers (1980) showed that maize dwarf mosaic virus strain-A had more pronounced effect on yield of maize when infection and subsequent disease development coincides with ear development. Early infection of sweet corn by MDMV at 3 and 8 leaf stage and just before silking, delayed maturity and reduced kernel fill and no significant difference in yield when inoculated at later stages compared to uninoculated control (Mikel et al., 1980). Significant yield loss upto 61% due to MDMV in maize was also reported by Jarjees and Uyemoto (1983).

Nagaraju et al. (1981) obtained highest incidence and complete loss of grain yield due to streak virus in ragi when plants

were artificially inoculated at less than 20 days of age. The virus adversely affected the plant height, ear head length, straw and grain yield and 1000 grain weight at all stages of inoculation. Alexander et al. (1984) reported yield reduction upto 75%, reduced height, panicle length in susceptible sorghum when MDMV-B was inoculated at three leaf stage. Premature death of seedlings sorghum accessions at early stages of infection by sorghum yellow banding virus and the reduction of grain yield by more than 50% in four sorghum inbreds was reported by Theu and Toler (1989).

Jensen et al. (1985) used ELISA to measure the concentrations of maize dwarf mosaic virus-A (MDMV-A) in various tissues of grain sorghum. The results indicated that the youngest leaf contained much less virus than older leaves, high levels of virus in all parts of plants but the virus disappeared in grain when plant reached physiological maturity stage. The results of Lei and Agrios (1986) also showed that MDMV virus in susceptible corn spread faster towards the proximal than distal end of leaf.

The virus spreads slowly towards both ends in resistant leaves suggesting that the plant inhibits the virus movements through leaf vascular system. Maximum variation in maize mosaic virus titre with 5th and 6th leaf was observed by ELISA test. The ELISA values progressively increased from the leaf base towards the tip of the leaf (Seifers and Caceres, 1988). The resistance mechanism expressed at a specific point of systemic virus transport limiting the upward movement of virus from the

roots to young developing leaves as reported in case of maize dwarf mosaic virus (Law et al., 1989).

Tsai (1975) reported the corn disease transmitted by P. maidis in Florida. The minimum incubation period of young plants was 4 to 6 days and 30 to 45 days in older plants. The per cent of infection decreased and the incubation period increased with the age of the host plant. Narayanaswamy (1972) reported that the age of the rice plants at inoculation with rice tungro virus by Nephotettix impicticeps influenced both the ability of the inoculated plant to act as source and recovery of the virus by the insect. Duffus and Skoyen (1977) reported that beet curly top virus in field caused serious losses even when inoculated as late as 10 weeks after seeding or after more than 40 per cent of the growing period elapsed. Both root yield and sucrose content were reduced significantly.

2.8 Inoculation techniques

Sakurai et al. (1964) developed a seedling test method for screening rice cultivars for stripe virus and the reactions of each cultivar rated on A to D (A = highly susceptible and D = highly resistant) 3 to 4 weeks after transplanting. Ling et al. (1970) developed mass screening for testing the resistance of rice varieties to grassy stunt disease of rice based on interaction between the causal agent of the disease and its insect vector Nilaparvata lugens (Stal.). Insects were reared for making them viruliferous and used to inoculate seedlings.

The average per cent of infected seedlings were used to evaluate the reaction. Varieties that showed low per cent infection were to be re-tested.

Garud and Mali (1981) screened sorghum germplasm against sorghum red stripe and the reactions of sorghum rated, 38 highly susceptible (HS), 36 susceptible (S), 1667 moderately susceptible (MS), 43 Tolerant and 27 as immune. Ten plants for each sorghum entry were raised from healthy seeds in earthen pot and inoculated mechanically at 3 leaf stage using extracts of red stripe virus infected leaves.

Martin and Hackeroff (1982) developed a greenhouse seedling test to determine the reaction of sorghum to MDMV-A and compared with results of field tests. Greenhouse tests were as accurate as field tests in identifying resistant and susceptible lines.

Lamey (1969) and Lamey et al. (1964) developed and perfected greenhouse test using Sogatodes oryzicola to save time and space and to reduce the number of plants to be handled. This became possible when methods were found increasing the percentage of active transmitters. Soto et al. (1982) developed methods for vector propagation and rapid and accurate screening of many accessions for virus tolerance in large screen houses and also for field evaluations. Viruliferous adults of Cicadulina mbila and C. triangula were released at the rate of 2-3 per plant and

disturbed twice a day for 10 days. A scale of 0-5 was used for evaluating tolerance to MSV.

Dabrowski (1985) reported mass rearing of *Cicadulina* have made it possible to infest experimental maize fields at IITA with as many as 180 to 100,000 viruliferous leafhoppers each week. Ten to fourteen days old maize seedlings were replaced with millet plants for oviposition and rearing of nymphs. Monitoring to find out the per cent active transmitters, in the populations helps to indicate the number of viruliferous leafhoppers which should be released per plant to secure 90-95% efficiency of MSV infections. Three leaf stage plants produced clear streak symptoms after 5 days of inoculation. Older plants required higher number of *cicadulina* adults and longer incubation period to produce symptoms.

Vann et al. (1985) reported seedlings were inoculated with MDMV A and B strains in greenhouse and field at 3-6 leaf stage and symptom expression was rated after 3 weeks. Of the 73 sudangrass accessions tested 2 were resistant, 50 intermediate and 21 susceptible. Zeigler et al. (1988) reported a method of rearing large colonies of viruliferous *Sogatodes oryzicola* vector for use in field screening. The insects released in the field when plants were 14 days old resulted in satisfactory disease incidence. Uniform infection of check varieties in the field indicated that the method was adequate to distinguish resistance from susceptibility. Sources of resistance was identified from 10,000 breeding lines.

2.9 Varietal resistance

Brewbaker and Aquilizan (1965) made genetic studies on resistance to corn mosaic and stripe transmitted by P. maidis. Under severe epiphytotics 93% of the resistant hybrids derived from the variety Hawaiiansugar were symptom free, while less than 3% of the susceptible inbreds were symptom free. Resistance was not observed in any commercial sweet corn hybrid. Fazli et al. (1970) reported differential reactions of selected sorghum and millet hybrid cultivars and accessions to strain of SCMV and MDMV. The amount of infection varied from 0 to 70%. Only two sorghum out of 13 exhibited resistance to different strains of viruses. The cultivar Wiley and Martin offered some degree of resistance to all viruses tested. Persley and Greber (1982) tested 14 sorghum genotypes to natural infection to sugarcane mosaic virus and found that QL-11 did not develop symptoms and virus was not detected following inoculation of samples to SCMV susceptible test plants. Henzell et al. (1982) developed 15 parental lines as resistance source to SCMV over 6 years. QL-19 conferred a high level of resistance to natural infection which averaged 13.5% infected plants in field over 3 years, compared with 79% in the recurrent parent KS-4. Langham et al. (1985) assessed disease severity in 26 sorghum varieties and hybrid populations by spraying 2 weeks old plants with MDMV and found that except QL-3 (Texas), QL-11 and QL-3 (India) all other accessions responded variously to 4 strains.

Choi et al. (1986) screened sorghum hybrids by mechanically inoculating in the greenhouse. The severity of symptom development rated on a 0-3 scale for each virus strain. MDMV-A and B, the percent infection for MDMV-A ranged from 30 to 100% and 0-95% for MDMV-B among the 58 hybrids screened.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present investigations on sorghum stripe virus (SStV) disease on sorghum was carried out during 1991-92 at Main Research Station University of Agricultural Sciences, Hebbal, Bangalore. The studies include standardization of penicillinase based enzyme-linked immunosorbent assay (PNC-ELISA) for detection of virus in host and vector, survey for incidence of SStV in Karnataka, virus-vector relationship, epidemiology, host range, effect on growth and yield and developing effective inoculation techniques for screening sorghum genotypes for resistant sources.

3.1 Virus culture

SStV culture used in the present investigation was collected from naturally infected sorghum (local fodder cultivar) field at Main Research Station, University of Agricultural Sciences, Bangalore during the end of 1990 and established in greenhouse (Fig. 1) at UAS, Bangalore. The established culture was confirmed as SStV by PNC-ELISA using antiserum raised against SStV which was obtained from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The virus culture was then increased on susceptible sorghum cultivar (SPV 351) and used for further investigations.

3.2 Planthopper culture

The delphacid planthopper Peregrinus maidis was also collected using aspirator from ratoon sorghum crop at MRS, UAS,

Fig. 1. Sorghum stripe virus disease culture.



Fig. 1

Hebbal, Bangalore and released on four weeks old healthy sorghum (cv. CSH 9) seedlings in insect rearing cages. The pure colonies of P. maidis were raised on four week old healthy plants by allowing one female and two males to produce next generation in an insect proof cage. Second and third instar nymphs were allowed individually to series of healthy sorghum seedlings at three to four leaf stage to make sure that the planthoppers do not carry SStV. Also group of insects were tested with ELISA and found not carrying virus. These planthoppers (Fig. 2a, 2b, 2c) were used for further experimentation.

3.3 Raising of healthy sorghum seedlings

The seeds of susceptible sorghum variety SPV 351 from ICRISAT and sorghum hybrid CSH 9 from Karnataka State Seed Corporation, Bangalore were procured for conducting experiments. The healthy seedlings were raised in polythene bags of size 4x3" and 6x5" containing farm yard manure mixed soil. Before sowing, seeds were pre-soaked in water for three hours, allowed to sprout for 24 hours in dark and then planted in polythene bags containing FYM mixed soil.

3.4 Preparation of cages for virus acquisition by planthoppers and inoculation technique

Plastic and polyvinyl chloride (PVC) bottles of different sizes (7.5 x 2.5 cm, 8x7 cm and 22x6 cm) and insect proof cages (60 cm height) were used to enclose plants for acquisition of

Fig. 2. Planthopper (Peregrinus maidis) cultures maintained on sorghum cultivar (cv. CSH 9)

- (a) First instar nymphs
- (b) 2-4 instar nymphs
- (c) Adults

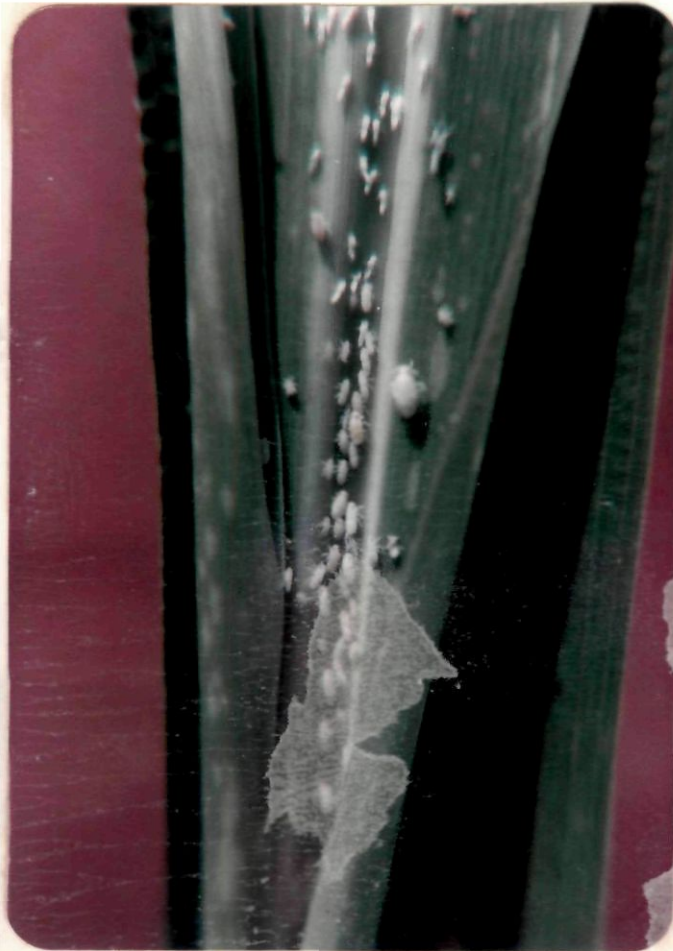


Fig. 2a



Fig. 2b



Fig. 2c

virus by planthoppers and for inoculations. Cages were prepared by removing the bottom portion and then covering with muslin cloth. A small hole was made on the wall of the cage for facilitating the release of planthoppers and plugged with cotton. The top 3 to 4 leaves infected with SStV were taken along with the cut stems and inserted into the round PVC bottle. The mouth of the bottle was plugged with the cotton along with the stem, so that the cut ends of the stem were immersed in bottle containing water (Fig. 3a). Two to three week old SStV infected plant was covered by using the PVC bottle (Fig. 3b). The healthy colonies of second and third instar nymphs which are convenient for handling were allowed inside the bottle to acquire the virus from infected leaves.

After allowing four days acquisition access period on SStV source plant, the insects were shifted on to 3-4 weeks old healthy plants and allowed for 10 days of incubation in metal framed cages (Fig. 4). The viruliferous insects were used to inoculate young seedlings (Fig. 5) and to conduct transmission studies.

3.5 Standardization of penicillinase based enzyme-linked immunosorbent assay (PNC-ELISA) for detection of virus in host and vector

A direct antigen coating method (DAC-ELISA) described by Hobbs et al. (1987) and modified by Sudarshana and Reddy (1989) was used to detect SStV virus in the host and the vector. Rabbit



Fig. 3a



Fig. 3b

Fig. 3. Methods for virus acquisition by planthopper

- (a) Infected sorghum stems along with leaves
- (b) Planthoppers allowed directly on infected plants

Fig. 4. Planthoppers allowed on healthy plants for incubation after acquisition in cages

Fig. 5a,b. Plastic vials used for inoculation sorghum seedlings with SSTV using viruliferous P. maidis



Fig. 4



Fig. 5a



Fig. 5b

FC-specific globulins prepared in goat (Sigma, USA) and conjugated to penicillinase enzyme was used.

The following steps were used for PNC-ELISA for SStV detection.

Materials:

1. ELISA polystyrene micro plate (Dynatech, Laxbro), 2. Antisera,
3. Adjustable multichannel micro pipette (range 100 to 1000 ul,
4. Carbonate buffer, 5. Phosphate buffer saline tween (PBS-T),
6. Enzyme labelled conjugate and 7. Substrate mixture.

Buffer and solutions

1. Carbonate buffer (Coating buffer)

Sodium carbonate	1.59 g
Sodium hydrogen carbonate	2.93 g
Distilled water	1000 ml
pH	9.6

2. Phosphate buffer saline (PBS)

Disodium hydrogen orthophosphate	1.44 g
Potassium dihydrogen orthophosphate	0.20 g
Potassium chloride	0.20 g
Sodium chloride	8.00 g
Distilled water	1000 ml
pH	7.4

3. PBS Tween (PBS-T)

1000 ml PBS + 0.05% Tween 20

4. Antibody buffer

PBS-T	100 ml
Polyvinyl pyrrolidone (PVP)	2.0 g
Ovalbumin	0.2 g

5. Substrate mixture

NaOH 0.2 N	50 ml
Bromothymol blue	20 mg
Benzyl penicillin (sodium)	2.0 mg/ml
pH	7.2

3.5.1 Detection of SStV in the host plant

Antigen preparation: Sorghum leaves infected with SStV were harvested and tissue was ground in coating buffer (1 g in 10 ml carbonate buffer) with the help of pestle and mortar. The extract was immediately filtered through a layer of muslin cloth and the extract was taken in watchglass. The required quantity was added to wells of ELISA plates.

Steps involved in PNC-ELISA

1. ELISA plates were coated with 100 μ l crude extracts of test antigen to each well and incubated overnight at 4°C after covering with lid.

Protocol : Penicillinase-based Enzyme Linked Immunosorbent Assay (PNC-ELISA)

1. Add test sample containing virus (1 gram in 10 ml coating buffer)

Incubate overnight at 4 C or 1 hr at 37 C

Wash in PBS-T, 3 changes of 3 minutes each
2. Add specific antibody after cross-absorption with healthy plant extract (1:1000)

Incubate for 3 hrs at room temperature or 1 hr at 37 C

Wash in PBS-T, 3 changes of 3 minutes each
3. Add FC-specific antibody conjugated with penicillinase (1:1000)

Incubate for 3 hrs at room temperature or 1 hr at 37 C

Wash in distilled water with 0.5% Tween 20, 3 changes of 3 minutes each
4. Add substrate mixture (50 ml of 0.2 N NaOH + 20 mg Bromo Thymol Blue + penicillin salt (2mg/ml) and pH adjusted to 7.2 before use)

Incubate for 1 to 2 h at room temperature
5. Assess the reaction visually, yellow as positive and blue as negative. Measure the loss of absorbance at 620 nm

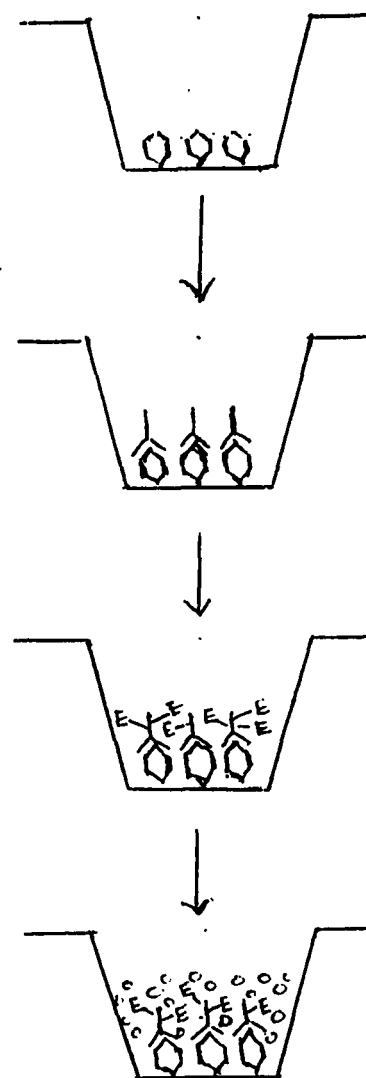


Fig. 6: Protocol for Penicillinase-based Enzyme Linked Immunosorbent Assay (PNC-ELISA) for the detection of sorghum stripe virus in host and planthopper.

2. After overnight incubation, the plates were washed in PBS-T buffer with three quick washes and three washes with three minutes interval. The plates were dried by tapping over a tissue paper pad.
3. Crude antiserum was diluted in antibody buffer and was cross absorbed with healthy leaf extracted in antibody buffer (for cross absorption the healthy tissue was ground in antibody buffer (1 g tissue/20 ml antibody buffer, crude antiserum was diluted in healthy leaf extract and suspended for 45 minutes at room temperature before use). One hundred microliter of diluted antiserum was added to each well and incubated for 3 h at room temperature.
4. Plates were washed in PBS-T as in step-2.
5. Penicillinase labelled anti-rabbit Fc-specific IgG conjugate was diluted (1:1000) in antibody buffer and 100 ul of this was added to each well. Plates were incubated for three hours at room temperature (25 to 30 C).
6. Plates were washed as in step-2 in distilled water with 0.05% Tween-20 and dried using tissue paper pad.
7. To each well 150 ul of the substrate mixture was dispensed (Substrate mixture : Dissolve 20 mg bromo-thymol blue (BTB) in 50 ml 0.2 M NaOH and neutralised with alkali by adding concentrated HCl dropwise. The volume was made upto 100 ml using distilled water. Sodium penicillin G at the rate of 2 mg per ml was added. The pH was adjusted to 7.2 using either 0.01 to 0.1 M HCl or NaOH before use). The

plates were incubated at room temperature (25 to 30 C) for further reactions.

Observations: The reactions were observed for 30 min to 2 hr and recorded the results either visually or by measuring the loss in absorbance at 620 nm.

Results: The blue colour of the substrate mixture first turns to bright green then light orange yellow and finally to yellow colour. A green colour indicates weak positive and orange yellow colour indicates strong positive. The reactions can be quantified by measuring the loss of absorbance at 620 nm. The results were also visually scored as positive (+) and negative (-).

3.5.2 Detection of virus in P. maidis

The viruliferous insects were assayed by PNC-ELISA test using individual and groups of 2, 5 and 10 insects. Insects were taken individually or in group in ependoff vials and ground in 250 ul carbonate buffer using como drill for one minute. One hundred microliter of the insect extract was dispensed in duplicate wells. The plates were processed similar to that for plant samples and results were recorded.

3.6 Survey

3.6.1 Survey for SStV incidence

A survey was undertaken in sorghum growing areas of

Karnataka (Fig. 7) during kharif and rabi 1991-92 to record the incidence of SStV disease. In each field, 10 spots of three m² area were selected at random and the total plants and infected plants were counted at each spot. Mean percentage of SStV infection was calculated and per cent incidence was recorded. During survey, information like location name, stage of the crop and date of survey were also recorded.

3.6.2 Survey for planthopper population

The vector incidence was surveyed during 1991-92 in farmers field at each selected locations. To estimate the field population of P. maidis, the direct count method was followed. Twenty plants were randomly selected in each field. The adult planthoppers were visually counted from top four whorls and recorded in each of the 20 randomly selected plants. The mean population of P. maidis per plant was estimated at each location surveyed.

3.6.3 Collection of disease specimen for ELISA test

During field survey SStV infected samples and suspected samples were collected. At each location, 5 to 10 samples of infected leaves were collected from each field. The leaf samples collected were cut into 5 cm length and packed in polythene bag to avoid drying during transit. The samples were labelled giving the details of sample number, location and date of collection. All the samples were brought to laboratory and stored at 4°C until further processing. Samples were then tested for ELISA.

KARNATAKA MAP

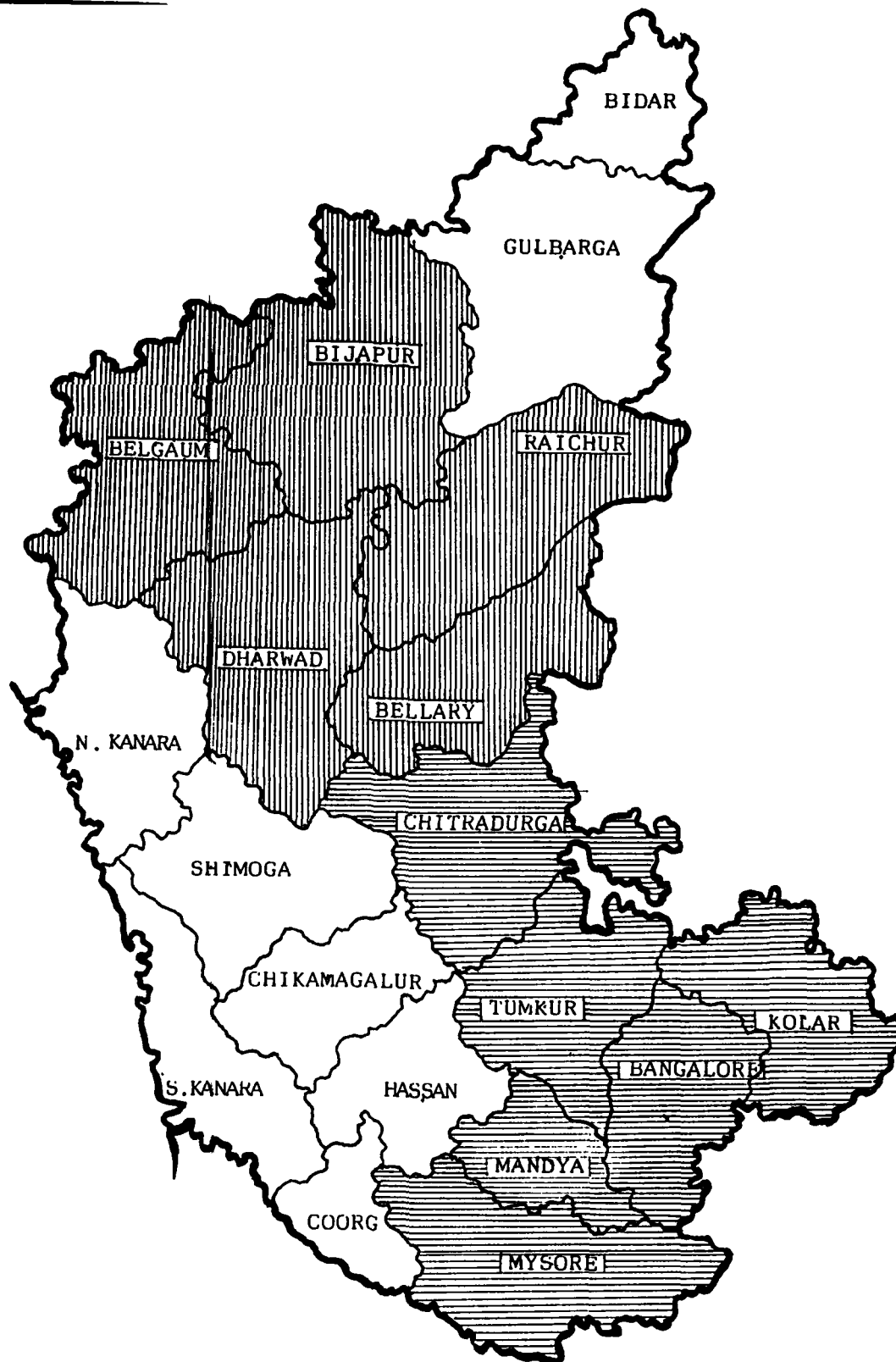


Fig. 7. Karnataka map showing the areas surveyed during kharif  and rabi  seasons for the incidence of sorghum stripe virus and planthopper.

3.7 Transmission

3.7.1 Insect transmission

Sorghum stripe virus and healthy planthopper (Peregrinus maidis) were used to study the virus-vector relationship. Susceptible sorghum cultivar SPV 351 was used as a test material for insect transmission studies. Seedlings were raised in polythene bags (4x3") containing well mixed soil and compost. Two leaf stages seedlings were used throughout the transmission studies. All acquisition access feedings were performed by confining groups of second and third instars nymphs on SStV infected sorghum plants in insect proof cages for four days followed by 10 days of incubation period on healthy sorghum plants unless otherwise mentioned. All inoculated seedlings were sprayed with insecticide monocrotophos (0.2%) at the end of inoculation access period and were maintained in insect proof cage for symptom expression.

3.7.2 Rate of transmission

To determine the rate of transmission of SStV by P. maidis, second and third instar nymphs were allowed to acquire virus on SStV infected plants in insect proof cages followed by 10 days for incubation on healthy plants. Five batches of 15 sorghum seedlings (2 leaf stage) were inoculated by confining seedlings with one viruliferous insect each using plastic vials (Fig. 5). Insects were allowed for 48 h IAP and then the vials and insects were removed. The seedlings were sprayed with 0.2% monocrotophos

and maintained in insect free cage for symptom expression.

3.7.3 Number of planthopper required for efficient transmission.

Second and third instar nymphs of P. maidis were allowed for four days to acquire the virus on infected plants followed by 10 days incubation on healthy plants. Viruliferous insects of 1, 2, 3, 4, 5 and 10 were allowed on each seedling. Fifteen seedlings (4 to 5 leaf stage) were inoculated under each group of planthoppers. Insects were allowed 48 h IAP, then removed and the plants were sprayed with 0.2% monocrotophos and kept in the greenhouse for symptom expression.

3.7.4 Acquisition access period (AAP)

To determine the AAP, a group of second and third instar nymphs of P. maidis were confined on whorls of infected plants in insect proof cage. Insects were allowed to feed for 1, 2, 4, 8, 12, 16, 20, 24, 48, 72 and 96 h for acquisition. At the end of each AAP, a group of insects were drawn and enclosed on 15 healthy seedlings (1-2 leaf stage). Two insects were confined to each seedlings in small vials. Insects were allowed to feed on seedlings for 10 days to complete latent period and IAP. At the end of 10 days, the seedlings were sprayed and maintained in greenhouse for symptom expression.

3.7.5 Incubation period of SStV in planthopper

A large number of second and third instar nymphs of

P. maidis were allowed for 24, 48, 72, 96 and 120 h of AAP on SStV infected plants. At the end of each AAP, the insects were transferred on to healthy plants. After 2 days on healthy plants, ten seedlings were inoculated at the rate of 2 insects per seedling. After every 48 h, the same insects were transferred to next series of healthy seedlings. The inoculated seedlings were then sprayed with insecticide and maintained in glasshouse till the symptom expression or for three weeks. The number of days required for symptom expression at each AAP was recorded. In another experiment, the length of incubation period of virus in the vector on transmission efficiency was studied. The healthy II and III instar nymphs were allowed 4 days of AAP followed by 4, 8, 12, 16, 20 and 24 days of incubation period enclosing on healthy plants. At the end of each incubation period, 15 healthy seedlings were inoculated 48 h IAP. Insects were removed and seedlings were maintained in glasshouse for symptom expression. The per cent transmission was recorded separately for each incubation period.

3.7.6 Inoculation access period (IAP)

Second and third instar nymphs of *P. maidis* were allowed 4 days of aquisition access period followed by 10 days incubation period. The insects were allowed IAP of 1, 2, 4, 8, 12, 16, 20, 24, 48, 72 and 96 h on healthy seedlings (2 leaf stage) using small plastic cages/vials. At the end of each IAP the insects were removed and the seedlings were shifted to greenhouse for symptom expression.

3.7.7 Persistence of virus in P. maidis

The persistence of SStV in P. maidis was determined by serial inoculation experiments. Healthy second and third instar nymphs were allowed 4 days AAP on infected plants and 10 days incubation period on healthy sorghum plants. Then 20 individual planthoppers were released on sorghum seedlings (2 leaf stage) separately. The planthoppers were serially transferred on to healthy sorghum seedlings at every 48 h intervals until the death of insects. After each IAP, seedlings were sprayed with 0.2% monocrotophos and kept in insect proof glasshouse for establishment and symptom expression. The symptom expression was recorded in each batch separately once a week upto one month.

3.7.8 Transovarial transmission of SStV

The method described by Gingery et al. (1981) and Tsai and Zitter (1982) was used with slight modification for transovarial transmission. The adult viruliferous females were confined to a batch of 20 sorghum seedlings and allowed 48 h IAP. At the end of IAP all the 20 females from inoculated seedlings were removed and shifted to fresh batch of healthy seedlings individually and maintained till the expression of SStV symptoms in the first batch of seedlings. When the seedlings of first batch expressed SStV symptoms, the same female insects maintained in second batch of seedlings were collected and allowed individually on to healthy plants (3 weeks old) in insect proof cage for laying eggs. Eggs which were at late development stage were

excised from the midrib of sorghum plant, placed on fresh healthy leaf pieces in petridishes with moist filter paper. The young emerged nymphs were confined singly on to healthy seedlings (1 leaf stage) and allowed 10 days to complete IAP and incubation. The young nymphs from healthy colonies were fed on healthy seedlings as control.

3.7.9 Stages and forms of insects on SStV transmission

A group of first, second and third instar nymphs and adults were allowed to acquire virus on infected sorghum plants separately. All the stages of insects were allowed four days of acquisition and later 10 days of incubation period on healthy plants. From each stage, 2 insect/seedlings were inoculated to a batch of 15 seedlings separately and allowed 48 h IAP. At the end of IAP insects were removed and sprayed with 0.2% monocrotophos and shifted to greenhouse for expression of symptoms.

3.7.10 Efficiency of sex of P. maidis on transmission

A group of healthy second and third instar nymphs of P. maidis were allowed 4 days of AAP on infected sorghum plant and followed by 10 days of incubation period on healthy plant. Male and females from each of brachypterous and macropterous forms were separated and transferred individually on to healthy seedlings at the rate of one insect per plant. A batch of 15 seedlings for inoculation were used with each of male and females in each of brachypterous and macropterous forms. Insects were

allowed for 48 h of IAP and then removed. The inoculated seedlings were kept in greenhouse for symptom expression.

3.7.11 Effect of age of sorghum on transmission

Three viruliferous adults of P. maidis were released on to individual healthy sorghum (cv: SPV 351) plants. Different growth stages namely, coleoptile, 2, 4, 6, 8 and 10 leaf stages using small plastic vials at young stage and perforated polythene bags for adult stage. Fifteen seedlings individually inoculated for each stage of plant growth with three viruliferous insects. After 48 h of IAP the insects were removed from plants and maintained in glasshouse for symptom expressions.

3.8 Seed transmission

3.8.1 Detection of SStV at different stages of seed development using ELISA

ELISA was employed to detect SStV at different stages of seed development. Samples at pre-flowering, milky stage physiologically mature seed, dried seeds and glumes were collected from five SStV infected plants in the field and tested by ELISA for the presence of virus.

3.8.2 Growing out test for seed transmission

Sorghum plants with top 1,2,3 and 4 leaves infected with SStV in field were selected, five plants at each level of infec-

tion were labelled. Seeds were harvested separately from each plant threshed and dried thoroughly. Sixty five seeds from each ear were planted in earthen pot filled with well mixed soil and compost and maintained in insect free glasshouse for establishment of seedlings and symptom expression. At the end of six weeks, random samples of leaves from each of the three groups were taken and tested by ELISA for the presence of virus in the leaves.

3.9 Epidemiology

3.9.1 Incidence of SStV and planthopper

A field experiment was conducted located near Plant Virology greenhouse, MRS, UAS, Hebbal, Bangalore to record the field incidence of SStV and planthopper. Sorghum hybrid (CSH 9) was sown in three blocks measuring 33 M X 15 M area during post rainy season of 1991-92. The spacing of 45 cm between rows and 10 cm between plants was maintained. The incidence of SStV and planthopper populations were recorded once in 20 days in each block during the cropping period. The symptom expression in basal and nodal tillers were also recorded at the end of the season. Adult planthopper population count was taken from top four whorls from 20 randomly selected plants at regular interval. The suspected plants with short and bent earheads were tagged and observed for SStV symptom expression in ratoon crop.

3.9.2 Incidence of SStV and planthopper in ratoon sorghum

The ratoon crop was raised in the same field after main

sorghum crop(3.9.1). Immediately after harvest the field was cleaned, earthing up was done and applied basal dose of fertilizer. The field was irrigated for encouraging sprouting of stubbles. The expression of SStV in the suspected plants tagged before harvesting of main crop. The further incidence of SStV and planthopper population in ratoon crop was recorded once in 20 days throughout the cropping period.

3.9.3 Expression of SStV symptoms on sorghum plant under field conditions

The expression of symptoms of SStV on different positions of sorghum plant were assessed during the cropping season. Symptom expression was recorded apart from main plant, the number of plants expressed symptoms on nodal and basal tillers two weeks before the harvest of main crop. Plants which did not show visible SStV symptom but suspected to be infected by SStV based on characters like stunted growth, short peduncle and slight apical bending of earhead were tagged. The field was irrigated frequently to encourage sprouting of sorghum stubbles. The expressions of symptoms on suspected plants at the end of main crop were recorded 20 days after sprouting in ratoon sorghum crop.

3.9.4 Influence of successive/overlap cropping of sorghum on incidence of SStV and planthopper

Field experiment was conducted to know the effect of successive/overlap cropping on the incidence of SStV and

planthopper. A field plot measuring 6Mx16M was planted with sorghum hybrid(CSH 9) in furrows with a spacing of 45 cm between rows and 10 cm between plants during August 1991. The SStV incidence and planthopper counts were recorded from top four leave of random plants at 20, 40, 60 and 80 days after planting. The main sorghum crop was harvested during January 1992 and allowed for ratoon sorghum to establish from the main sorghum stubbles and maintained upto seed maturity. Observations on SStV infected plants and planthopper populations were recorded at intervals. Sorghum seeds were sown in furrows 2 weeks before the harvest of previous ratoon sorghum in an adjacent field measuring 5 x 15 M during May 1992. Observations on SStV incidence and planthopper populations on overlap sorghum crop were recorded similar to that on main and ratoon sorghum. Sorghum crop was maintained with frequent irrigation upto seed maturity stage.

3.9.5 Incidence, spread and distribution of SStV under field conditions

Sorghum crop was raised in the field during post rainy season 1991-92 at MRS, UAS, Hebbal, Bangalore to know the incidence, spread and distribution of SStV during the cropping season under natural conditions. The sorghum hybrid (CSH 9) was sown in the field measuring 16x16M with spacing of 40 cms between rows and 10 cms between plants. The plant population was counted when the crop was three weeks old. The field map was prepared and the SStV infected plants were mapped from the day of first appearance of SStV and later once in 15 days interval upto 120

days. Adult planthopper population was counted from top four whorls of 20 random plants representing the entire field at each interval.

3.9.6 Distribution pattern of SStV in field condition

To determine the distribution pattern of SStV under field conditions observations of SStV infected plants were recorded at the time of flowering in sorghum (SPV 351) field during rabi season 1991 at MRS, UAS, Bangalore. The entire field was divided into 7 sampling units of 10 rows each with 400 plants per row. Observations on number of SStV infected plants in each row were recorded and the data were analysed to work out the distribution patterns (Ludwig and Reynolds, 1988).

$$\bar{X} = \frac{x}{n}$$

Where, $\bar{X}$ = Mean number of infected plants
 x = Number of infected plant/row
 n = Total number of plants/row

$$S^2 = \frac{(x - \bar{X})^2}{n}$$

Where S^2 = Variance

$$K = \frac{x^2}{S^2 - \bar{X}}$$

Where K gives the measures of dispersion, smaller the value of K (<1) greater the extent of aggregation or clumping.

$$GI = \frac{(S^2/\bar{X}) - 1}{n - 1}$$

GI refers to green index and it varies between 0 (randomly) and 1 (for maximum clumping). Where GI measures the degree of clumping.

The distribution pattern was defined based on the variance (σ^2) to mean (μ) relationships where

$\sigma^2 = \mu$: random or poisson distribution

$\sigma^2 > \mu$: clumped or negative binomial distribution

$\sigma^2 < \mu$: Uniform or positive binomial distribution

The initial null hypothesis is that, the number of individuals of infected plant per sampling unit is random. If this hypothesis is rejected then the distribution may be in the direction of clumped (usually) or uniform (rarely).

3.9.7 Effect of field population of P. maidis on SStV transmission

Two groups of P. maidis insects were collected from the field. The first group of insects were collected from the SStV infected plants. Another group of insects were collected from uninfected plant. Both the groups of insects were inoculated to healthy seedling by following two methods. Insects from both the groups were inoculated to individual seedling at the rate of two insects per seedling. In the second method group of 40 seedlings was inoculated by releasing 80 insects in a rectangular container at two leaf stage and covered the top with muslin cloth. Insects were allowed for one week inoculation access period. They were then removed from seedlings, sprayed with 0.2% monocrotophos and

the seedlings were maintained in greenhouse for establishment and symptom expression for a period of four weeks.

3.9.8 Survival of SStV on storage

Sorghum leaves showing SStV symptoms were collected from infected plant. Small pieces of one gram weight were packed in small polythene covers. A set of 12 samples were stored each at -10°C and another set at $5-8^{\circ}\text{C}$. The samples from both were drawn on first week of every month (August 91 to August 92) and processed for ELISA and the reaction of each sample was recorded.

3.9.9 Weather parameters in relation to incidence of SStV and planthoppers

The weather parameters like rainfall, temperature and relative humidity were recorded during 1991-92 at Main Research Station, UAS, Bangalore where the experiment was conducted. The weather parameter and its influence on SStV incidence and vector populations were correlated.

3.10 Host range

3.10.1 Cereals, fodder and weed grasses

Host range studies for SStV were carried out on cultivated crops viz., rice, wheat, maize, finger millet, pearl millet, navane, paspalum, barnyard millet, sugarcane, fodder and weed grasses and five cultivars in each host. A group of 15-20 seedlings was raised from seeds or suckers in a polythene bag containing mixture of soil and farm yard manure. At two to three

leaf stage, each group of test seedlings was inoculated by releasing 30 to 40 viruliferous adult *P. maidis* insects and covered with PVC bottles with open top covered with muslin cloth. At the end of 72 h of IAP, active insects were counted and plants were sprayed with 0.2% monocrotophos. The inoculated plants were maintained in glasshouse for symptom expression. Four weeks after inoculation leaf samples were collected from each host and processed for ELISA.

3.10.2 Host range of planthoppers in natural colonization on grasses and artificial testing

Several fodder varieties maintained in field continuously for 6 years at Main Research Station, UAS, Hebbal, Bangalore were surveyed for the natural colonization of planthopper. 20 varieties of fodder grasses were maintained near glasshouse adjacent to planthopper infested sorghum sick plot (Fig. 8). Fodder and weed grasses found in and around the sorghum field were also surveyed for planthopper throughout the year. 15 to 20 seedlings of graminaceous cultivated fodder and weed grasses were raised in polythene bag/earthen pot and artificially inoculated using viruliferous adult planthoppers. The planthoppers were allowed to feed for 3 days and the survival of the planthopper recorded at the end of 3 days feeding period.

3.11 Effect of SStV on plant growth and yield

3.11.1 Effect of SStV on chlorophyll, NPK content and other growth parameters

Fig. 8. Fodder grass species maintained for testing host range of
SStV and planthopper



Fig. 8

Sorghum seedlings were raised at 1-2 leaf stage and were inoculated with 2 adult viruliferous insects per seedling in cage and allowed 48 h IAP. The experiment was conducted in three replication. The infected seedlings were allowed to establish in greenhouse for symptom expression. Similarly uninoculated seedlings were maintained in glasshouse which served as control. One month after inoculation, the plants were harvested and growth parameters like plant height, number of leaves, leaf area, chlorophyll content, fresh and dry weight of shoots and roots and NPK analysis of both shoot and roots were analysed (Jackson, 1967).

3.11.2 Effect of SStV on plant growth parameters at various stages of infection.

To demonstrate the effect of SStV on plant growth parameters at various growth stages, an experiment was conducted under glasshouse conditions. Sorghum (cv. SPV 351) seedlings were raised in polythene bag and allowed to establish in greenhouse. When plants were at 2, 4, 6, 8 and 10 leaf stage, 15 plants at each stage were inoculated at the rate of 5 adult viruliferous insects per plant using plastic vials for young seedlings. The top 3-4 whorls of plants were covered with perforated polythene bag (10" size) and stapled the bags at the bottom of polythene bag along with the stem for grown up plants. Through a small insertion at the top of polythene bag, the adult viruliferous insects were released and plugged with cotton. The insects were allowed 48 h of inoculation access period and removed. Then the

plants were sprayed with 0.2% monocrotophos and maintained in insect free glasshouse for growth and symptom expression. Plants were harvested after the emergence of earhead and plant growth parameters (plant height, number and length of internodes, fresh and dry weight of shoot and roots) were recorded. Observations in healthy plants at each growth stage was recorded to serve as control.

3.11.3 Detection of SStV in different parts of sorghum plant

Sorghum infected plant with SStV (cv. SPV 351) were pulled out from the field along with the roots at the time of seed initiation stage. Sampling was made from different parts of the plant and processed for PNC-based ELISA for SStV detection. The presence or absence of SStV in different parts were visually scored and recorded as positive or negative.

3.11.4 Estimation of SStV virus titre in leaves of infected sorghum plant

SStV infected plants showing symptoms were selected in the field at flowering stage. The total number of leaves were counted from the base towards the tip of plant. The leaves which showed the first initial symptom from the base and then subsequent infected leaves towards the tips were numbered (6 to 11). From each leaf, one gram of infected tissue was taken and processed for ELISA to estimate the virus titre from each of the infected leaves.

3.11.5 Effect of SStV infection on plant growth and grain yield of sorghum

A field experiment was designed at Main Research Station, Hebbal, Bangalore to demonstrate the effect of SStV infection on plant growth and grain yield at various stages of infection. Sorghum (cv. SPV 351) seeds were sown in three replicated plots, each plot measuring 15x15 M. Adult viruliferous insects colonies were raised in greenhouse by allowing second and third instar nymphs on infected plants for 4 days followed by 10 days incubation on healthy plants. Twenty to twentyfive plants were selected each at 20, 25, 30, 35, 40 and 45 days after emergence. The total number of leaves at each growth stage were recorded at the time of inoculation. Adult viruliferous insects were inoculated to each plant at the rate of 4-5 per plant enclosing in perforated polythene bag (Fig. 9). The inoculated plants were labelled individually at each growth stage. The insects were allowed 2-3 days of IAP and removed along with plastic cover. When the plants reached physiological maturity, the total number of leaves per plant and plant height of infected and healthy plants were recorded at each growth stage. From each growth stage, 10-15 infected plants per replication were harvested individually and the grain yield per plant was recorded. Similarly grain yield harvested from healthy plant served as control. The data from all the growth stages were analysed statistically for estimating loss of grain yield.

Fig. 9. Inoculation of sorghum plants with SStV under field conditions using perforated polythene bag



Fig. 9

3.12 Inoculation techniques

3.12.1 Threshold levels of insects for efficient SStV transmission

A batch of 10 seedlings per bag was raised upto 2-3 leaf stage. The adult viruliferous insects of 1, 2, 4, 8, 12, 16 and 20 insects per bag were enclosed to inoculate using PVC bottles as cages. Each level was replicated five times. The insects were removed after 48 h of IAP and the seedlings were sprayed with insecticide and maintained in glasshouse for expression of symptoms. The per cent infection of SStV was recorded at each level of insects used for inoculation.

3.12.2 Inoculation of individual seedlings

Individual seedlings (2 leaf stage) were raised in small polythene bags. Two adult viruliferous insects were confined to each seedling using plastic vials as cages and allowed 48 h of IAP. The seedlings were sprayed with 0.2% monocrotophos and shifted to glasshouse for symptom expression.

3.12.3 Inoculation of group of seedlings

A group of ten seedlings were raised in each of the polythene bags upto two leaf stage. Then seedlings were covered with PVC bottles (20 cm long and 7.5 cm diameter) with provision for aeration and release of insects. Adult viruliferous insects of 10 and 20 were transferred to each group of seedlings in batches. Insects were allowed 48 h of IAP and then separated

from the seedlings and maintained in glasshouse for expression of symptoms.

3.12.4 Mass inoculation of sorghum seedlings in rectangular container

In this method large population (40 to 50) of sorghum seedlings were raised in rectangular container (50 x 28 cms size) containing well mixed soil and compost. When the seedlings were at 2 to 3 leaf stage the top surface of the container was covered with 40 mesh nylon cloth and tied firmly using thread along the margin from outside. A small hole was made at one end to facilitate the release of viruliferous insects. Adult viruliferous insects were released inside the rectangular box at the ratio of 1:2 (seedlings vs insects) and allowed 48 h IAP. The insects were removed at the end of IAP and maintained in insect free glasshouse for symptom expression.

3.12.5 Inoculation of grownup sorghum plants

Sorghum plants were raised in polythene bags/earthen pots upto 6-8 leaf stage and used for SStV inoculations. The top portion of plants partially removed to the levels of 3 inches above the last emerging leaf to facilitate the covering of 3-4 whorls from top. The perforated polythene bags were covered from the top of the plant in such a way to cover 3-4 whorls and stapled at the bottom of the polythene bag along with the stem. Small insertion was provided for the release of insects at top of

the perforated cover. Four to five adult viruliferous insects were released into the whorls through the opening and plugged the hole with cotton. After the insects were allowed 48 to 72 h inoculation access period, the polythene cover and insects were removed at the end of IAP. Plants were maintained in glasshouse for symptoms expression.

3.12.6 Comparison of different inoculation technique for SStV transmission

Five inoculation methods described above (Fig. 45) were compared in replicated trials. The seedlings were raised in polythene bags. The seedlings were inoculated according to the methodology described earlier. In each inoculation method, adult viruliferous planthoppers were used at the rate of two insects per seedlings. The insects were allowed to feed for 48 h on test seedlings and removed and the plants were sprayed with 0.2% monocrotophos and maintained in glasshouse for symptom expression for 3 to 4 weeks. Flow chart for group inoculation technique is given in Fig. 46.

3.13 Varietal screening

Sorghum lines consisted of 28 germplasm belonging to different races of sorghum, 40 genotypes from breeding lines, 55 genotypes of hybrids and varieties and 30 genotypes which were resistant to other sorghum diseases such as downy mildew, anthracnose, leaf blight, charcoal rot, rust and grain mold were procured from International Crop Research Institute for the Semi-

arid Tropics (ICRISAT) Patancheru, Hyderabad, India. Another 40 genotypes consisting of advanced varietal lines were procured from National Sorghum Research Center, ICAR, Hyderabad. All the above sorghum genotypes were screened for sorghum stripe virus reactions using the group seedling inoculation technique as described under 3.12.3. Fifteen to twenty seedlings from each cultivar were screened to evaluate the reaction to SStV and per cent infection was calculated based on the total number of seedlings inoculated to number of infected seedlings.

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

4.1 Standardization of penicillinase based enzyme linked immunosorbent assay (PNC-ELISA) for detection of sorghum stripe virus (SStV) in host and planthopper (Peregrinus maidis).

4.1.1 Detection of SStV in the host

PNC-ELISA was standardized and successfully used to detect SStV in sorghum and other hosts using antiserum produced against SStV (Fig. 10). ELISA results (Table 1) showed that the SStV could be detected in infected leaf extracts with host dilution of 1: 6250. The antiserum dilution of 1: 20,000 could be used with highest host dilution of 1: 6250. The absorbance value of 1.836 was obtained when antigen and antiserum were diluted to 1:50 and 1:1000, respectively.

4.1.2 Detection of SStV in planthopper (P. maidis)

Second and third instar nymphs of P. maidis were allowed 4 days acquisition access period (AAP) on SStV infected plant and 10 days incubation period (IP) on healthy plants. The individual and group of 2, 5 and 10 plant hoppers were used for detection of SStV by ELISA (Fig. 11). The results (Table 2) indicate that SStV antigen could be detected upto 40 per cent of the population when individual insects were used. The detection percentage increased upto 50, 80 and 100 per cent when group of 2, 5 and 10 insects were used for testing.

Table 1: Penicillinase-based enzyme linked immunosorbent assay (PNC-ELISA) for detection of sorghum stripe virus at various antigen and antiserum dilutions.

Antigen dilution ^a		Absorbance readings ^b . Dilution of antiserum				
		1:1000	1:5000	1:10000	1:15000	1:20000
Infected	1/50	1.836	1.724	1.603	1.506	1.426
	1/250	1.713	1.471	1.325	1.320	1.130
	1/1250	1.620	1.346	1.290	1.147	1.053
	1/6250	1.534	0.993	0.777	0.667	0.611
Healthy	1/10	0.000	0.000	0.000	0.000	0.000
	1/50	0.000	0.000	0.000	0.000	0.000

a Original tissue diluted using coating buffer (1 g/10 ml)

b Mean absorbance values of duplicate wells at 630 nm obtained after deducting the mean absorbance value of buffer control.

Table 2: Detection of sorghum stripe virus in planthoppers Peregrinus maidis by Penicillinase-enzyme linked immunosorbent assay (PNC-ELISA)

Number of ^a insects	Number of ^b samples	Positive to ELISA	Per cent detection
1	10	4	40.0
2	10	5	50.0
5	10	8	80.0
10	10	10	100.0

^a AAP 4 days, latent period 10 days

^b Each sample tested in duplicate wells

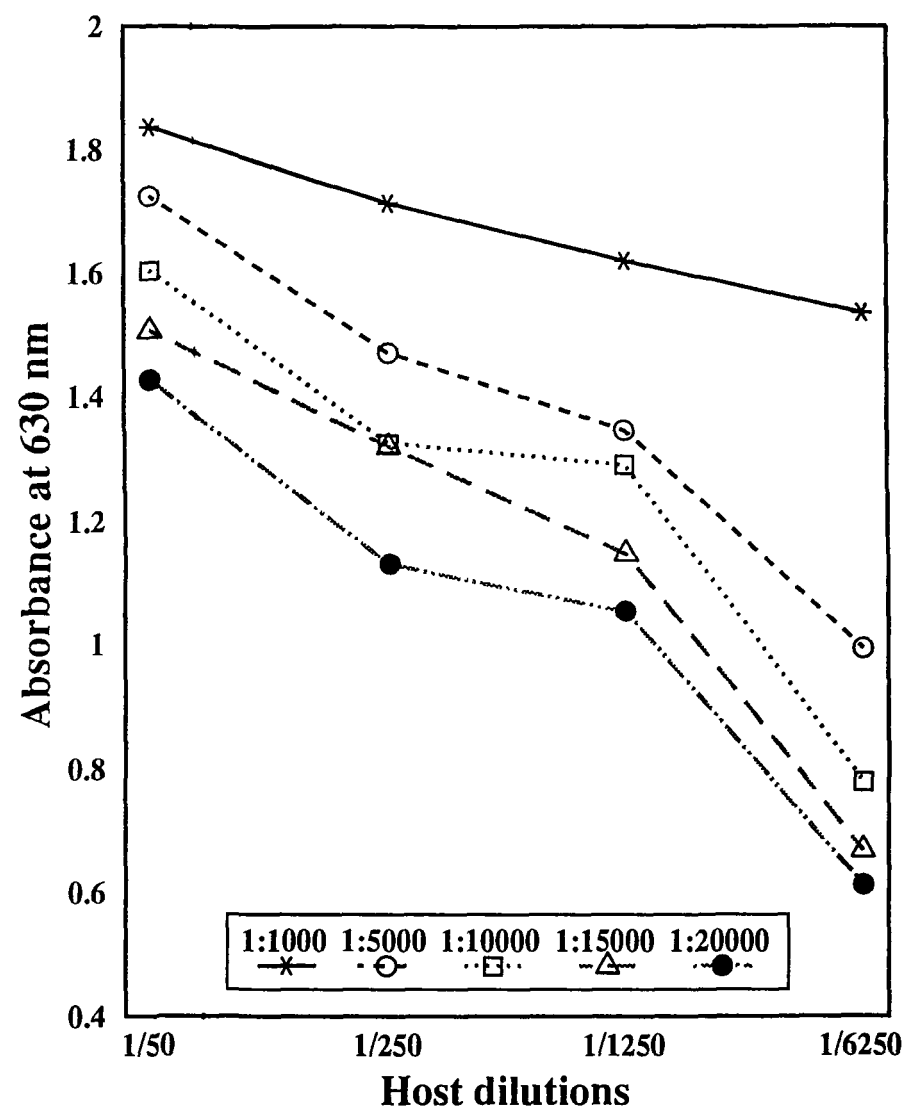


Figure 10. Detection of SSStV by polyclonal antibodies at different dilutions

Fig. 11. ELISA plate showing positive reaction (yellow) to virus
carrying planthopper

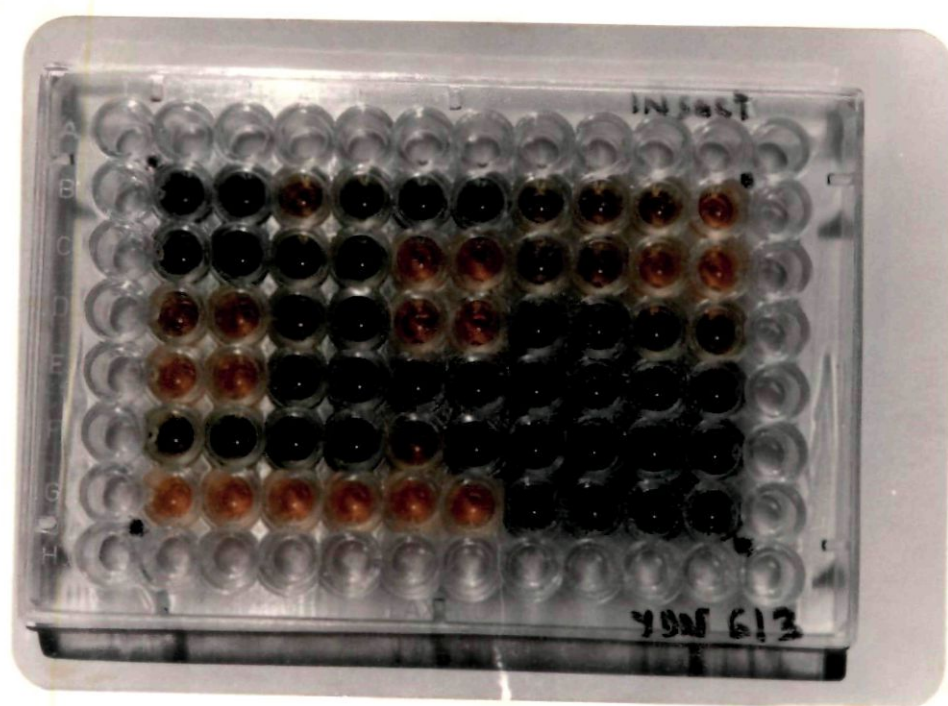


Fig. 11

4.2 Symptomatology

The sorghum stripe virus disease on sorghum is characterised by continuous chlorotic stripes and bands along the veins (Fig. 12). The symptoms initially consisted of stippling and overlapping circles aligned in rows parallel to the veins progressing from the base leaf towards the tip of chlorotic bands (Fig. 13) and in advanced stages the stippling /circles coalesce and form clear stripes. The leaves emerging later appeared completely yellow devoid of chlorophyll (Fig.14). The plants infected at early stages became stunted with short internodes and produced poorly developed panicles with few grains. The SStV infected plants in advanced stages showed characteristic apical bending of ear (Fig. 15) with short peduncle compared to healthy sorghum plants. The SStV infected sorghum plant collected from the field survey showed characteristic stripe symptoms on the top four leaves with partial emergence of earhead (Fig. 16).

4.3 Survey for incidence

4.3.1 Incidence of sorghum stripe virus (SStV)

The survey for SStV incidence was undertaken in eleven districts of sorghum growing areas of Karnataka during kharif and rabi seasons of 1991-92 (Fig. 7). The survey (Table 3) showed that the incidence of SStV disease in 14 locations in Southern Karnataka during kharif ranged from 0 to 13.5 per cent with an average incidence of 4.0 per cent. The incidence of disease in

Fig. 12a SStV infected sorghum leaves showing characteristic chlorotic stripes and bands

Fig. 12b Field SStV infected sorghum plant with partial emergence of earhead



Fig 12a



Fig. 12b

Fig. 13. Symptoms of SStV progressing from base of the leaves towards the tip with yellowspot/circles

Fig. 14a. Sorghum plant showing severe infection of SStV
1. Disease 2. Healthy

Fig. 14b. Sorghum ear head showing severe infection of SStV 1. Disease 2. Healthy



Fig. 13



Fig. 14a



Fig. 14b

Fig. 15. Sorghum earhead showing apical bending at later stages of SStV infection

Fig. 16. Sorghum plants infected under field conditions showing chlorotic stripes on the leaves and partial emergence of earhead



Fig. 15



Fig. 16

23 locations in northern Karnataka ranged from 2.8 to 7.0 per cent with an average of 5.4 per cent. The data on mean and range of SStV and planthopper incidence over locations surveyed presented in Table 4.

4.3.2 Incidence of planthopper (Peregrinus maidis)

The incidence of planthopper was surveyed in eleven districts of sorghum growing areas in Karnataka during kharif and rabi seasons 1991-92. The survey (Tables 3 and 4) showed that average incidence of planthopper population per plant varied from 1 to 6 in 37 locations surveyed. The data also indicated the incidence of planthopper in all sorghum fields surveyed in both kharif and rabi seasons.

4.3.3 ELISA based survey for SStV incidence

During the survey for incidence of SStV in sorghum growing areas of Karnataka. 276 sorghum leaf samples infected or suspected to be infected by SStV were collected from 37 locations and tested by ELISA in the laboratory for SStV infection. The results presented in (Table 5) showed that out of 276 leaf samples collected, 197 samples reacted positively to SStV antiserum when tested by PNC-ELISA (Fig 17a & 17b). The data also indicate the incidence of SStV in most of the sorghum growing areas in Karnataka during 1991-92.

4.4 Transmission

4.4.1 Insect transmission

In nature the sorghum stripe virus was transmitted by del-

Table 3: Survey for the incidence of sorghum stripe virus disease and planthopper (*Peregrinus maidis*) populations in sorghum growing areas of Karnataka during kharif and rabi 1991-92.

Districts	Location	Date of collection	Stage of crop	Per cent incidence	Vectors/plant
Mysore	Nagenahally	26-6-91	6 leaf	2.0	1.0
	Bhogodhi	26-6-91	8 leaf	2.0	3.0
Mandya	Sathnur	27-6-91	6 leaf	0.0	2.0
	Mandya	27-6-91	Flower	0.0	4.0
Bangalore	Marasandra-1	14-7-91	8 leaf	13.5	2.4
	-2	14-7-91	Flag leaf	10.0	2.0
	Hebbal-1	10-11-91	Grain filling	10.0	2.8
	-2	10-11-91	Grain filling	8.5	2.4
Kolar	Kolar	21-8-91	Flag leaf	0.0	1.5
	Kagathi	21-8-91	8 leaf	0.0	2.0
Chitradurga	Hiryur	28-8-91	Flag leaf	1.4	1.6
	Belhal	28-8-91	Flowering	3.2	2.0
Tumkur	Devarayapatna	11-9-91	8 leaf	3.1	3.8
	K.G. hally	10-12-91	Flowering	5.4	4.2
Dharwad	Agri. College	17-12-91	Grain filling	5.9	2.4
	Dharwad	17-12-91	Flowering	4.9	3.2
	Kamdolly	18-12-91	Flag leaf	3.8	1.4
	Kumgol	18-12-91	Flag leaf	5.7	1.8
Belgaum	Halaga	19-12-91	8 leaf	5.0	2.4
	Yaragatti	19-12-91	Flag leaf	5.4	2.9
	Chandargi	19-12-91	Flowering	7.0	2.6
	Ramadurga	20-12-91	Flowering	6.0	3.0
	Soundathi	20-12-91	Flag leaf	6.3	3.6
Bijapur	Bijapur	20-12-91	Flowering	4.2	2.1
	Jamakandi	20-12-91	Flag leaf	4.8	2.2
	Mudhol	20-12-91	10 leaf	4.3	3.0
	Lokapur	20-12-91	10 leaf	5.8	3.6
Raichur	Raichur	16-1-92	Hard dough	2.8	2.0
	Agril. College	16-1-92	Flag leaf	4.4	6.0
	Vadavatti	16-1-92	Flag leaf	3.3	2.0
	Kollur	17-1-92	Grain filling	3.0	2.1
	Manvi	17-1-92	Milk stage	4.0	2.7
	Sindhanur	17-1-92	Milk stage	4.1	2.3
Bellary	Tirumalanagar	18-1-92	Flag leaf	4.1	5.9
	Siruguppa	18-1-92	Flag leaf	4.5	2.5
	Hospet	18-1-92	Grain filling	3.4	4.0
	Munirabad	18-1-92	Grain filling	4.1	2.7
Average	37			4.48	2.7

Table 4: Mean and range of SStV and planthopper incidence over locations surveyed in sorghum growing districts of Karnataka during 1991-92

District	Locations	Season	Per cent incidence Mean (Range)	Vector ^a . population/p Mean (Range)
Bangalore	3	Kharif	10.4 (8.5-13.5) ^b	2.4 (2.0-4.8) ^b
Mandya	2	Kharif	0.0 (0.0-0.0)	3.0 (2.0-4.0)
Mysore	2	Kharif	2.0 (2.0-2.0)	2.0 (1.0-3.0)
Tumkur	2	Kharif	4.2 (3.1-5.4)	4.0 (3.8-4.2)
Kolar	2	Kharif	0.0 (0.0-0.0)	1.7 (1.5-2.4)
Chitradurga	2	Kharif	2.3 (1.4-3.2)	1.8 (1.6-2.0)
Dharwad	4	Rabi	5.0 (3.8-5.9)	2.0 (1.4-3.2)
Belgaum	5	Rabi	5.9 (5.0-7.0)	2.9 (2.4-3.6)
Bijapur	4	Rabi	4.7 (4.2-5.8)	2.7 (2.1-3.6)
Raichur	6	Rabi	3.6 (3.8-4.1)	2.9 (2.0-6.0)
Bellary	4	Rabi	4.0 (3.4-4.5)	4.0 (2.5-5.9)

^a Vector population is mean count of 20 individual plants from top four whorls at each location

^b Figures in parenthesis indicate range of infection and planthopper populations in each district.

Table 5: ELISA based survey for the incidence of sorghum stripe virus in sorghum growing areas of Karnataka during 1991-92

District	Location	Sample collection	Number of samples	ELISA positive
Mysore	Bhogodhi	June 91	5	5
	Nagenahally	June 91	5	0
Mandya	Sathanur	June 91	5	0
Bangalore	Marasandra	Aug. 91	15	12
	Hebbal	Aug. 91	10	8
Kolar	Kagathi	Aug. 91	10	0
Chitra-durga	Hiriyur	Aug. 91	12	8
	Belhal	Aug. 91	8	6
Tumkur	D.Patna	Sept. 91	9	8
	K.G.Hally	Dec. 91	15	12
Dharwar	Ag.College	Dec. 91	10	8
	Dharwar	Dec. 91	10	9
	Kamdolly	Dec. 91	11	8
	Kumgol	Dec. 91	10	7
Belgaum	Halga	Dec. 91	15	7
	Yaragatti	Dec. 91	6	4
	Chandargi	Dec. 91	6	6
	Ramdurg	Dec. 91	6	5
	Soundatti	Dec. 91	5	5
Bijapur	Bijapur	Dec. 91	8	5
	Jamkandi	Dec. 91	7	5
	Mudhol	Dec. 91	5	4
	Lokapur	Dec. 91	6	6
Raichur	Raichur	Jan. 92	8	8
	Ag.College	Jan. 92	10	7
	Vadavati	Jan. 92	12	9
	Kollur	Jan. 92	5	3
	Manvi	Jan. 92	6	5
	Sindhanur	Jan. 92	8	4
Bellary	Siriguppa	Jan. 92	5	5
	T.Nagar	Jan. 92	12	8
	Hospet	Jan. 92	6	5
	Munirabad	Jan. 92	5	5
Total	33		276	197

Fig. 17. ELISA plate showing positive (yellow) and negative (blue) reactions from leaf samples collected from field survey

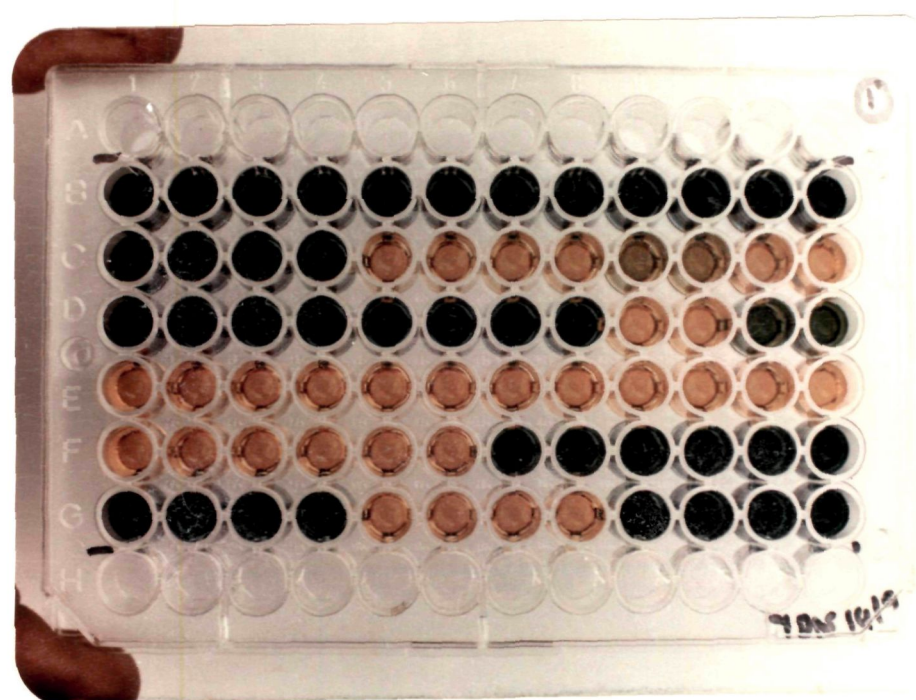


Fig. 17

phacid planthopper P. maidis. The detailed studies on biological relationship between SStV and its vector were worked out in glasshouse experiments and the results are presented below.

4.4.1.1 Rate of SStV transmission

Five sets of similar experiments were conducted in the greenhouse to know the rate of SStV transmission by P. maidis. The rate of transmission was found to be 53, 40, 46.7, 40 and 46.7 per cent respectively. The average rate of transmission was found to be 45.34 per cent (Table 6).

4.4.1.2 Number of P. maidis required for efficient transmission of SStV.

The results presented in Table 7 showed that minimum of five viruliferous planthoppers per plant could result in 100 per cent infection. The data also indicated that as the number of planthoppers per plant increased the percentage transmission was also increased (Fig.18). There is positive relationship ($r = 0.92$) between the number of insects per plant and per cent transmission.

4.4.1.3 Acquisition access period (AAP)

The results (Table 8) showed that the minimum acquisition access period required was 4 h. As the AAP increased, the per cent transmission was also increased (Fig. 19).

Table 6:Rate of SStV transmission by planthopper (P. maidis)^a.

Experiment number	Plants ^{b, c} infected	Per cent transmission
1	8	53.3
2	6	40.0
3	7	46.7
4	6	40.0
5	7	46.7
Mean	6.8	45.34

^a AAP 4 days, incubation period 10 days, IAP 48 hrs,
one insect/seedling.

^{b c} Total plants infected out of 15 seedlings.

Table 7: Effect of number of planthoppers (P. maidis) on SStv transmission of SStv

Number of ^a planthoppers	Plants ^{b, c} infected	Per cent ^d transmission
1	6.4	42.0
2	7.3	48.7
3	9.0	60.0
4	10.7	71.0
5	15.0	100.0
10	15.0	100.0

a AAP 4 days, incubation period 10 days, IAP 48 hrs

b 4-5 leaf stage seedlings used

c Plants infected out of 15 seedlings

d Mean of three experiments

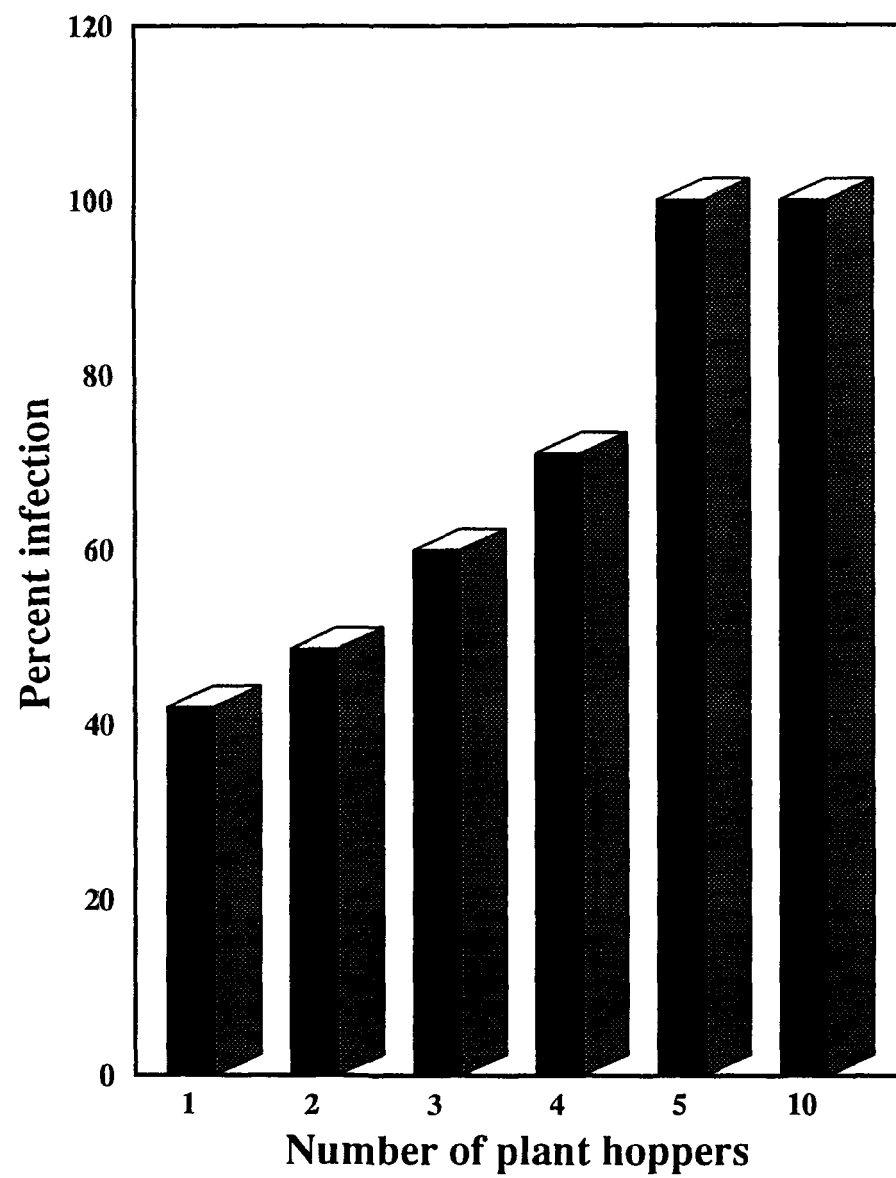


Figure 18. Number of plant hoppers on percent infection of sorghum stripe virus

Table 8: Effect of acquisition access period (AAP) by *P. maidis*^a on SSTV transmission

AAP (hours)	Plants ^b infected	Per cent ^c transmission
1	0.0	0.0
2	0.0	0.0
4	0.5	3.3
8	1.5	11.1
12	3.0	20.0
16	3.5	22.3
20	3.7	24.7
24	4.5	33.3
48	6.0	44.4
72	8.5	57.8
96	9.0	60.0

^a AAP 48 hrs, latent period 10 days

^b Plants infected out of 15 seedlings

^c Mean of three experiments

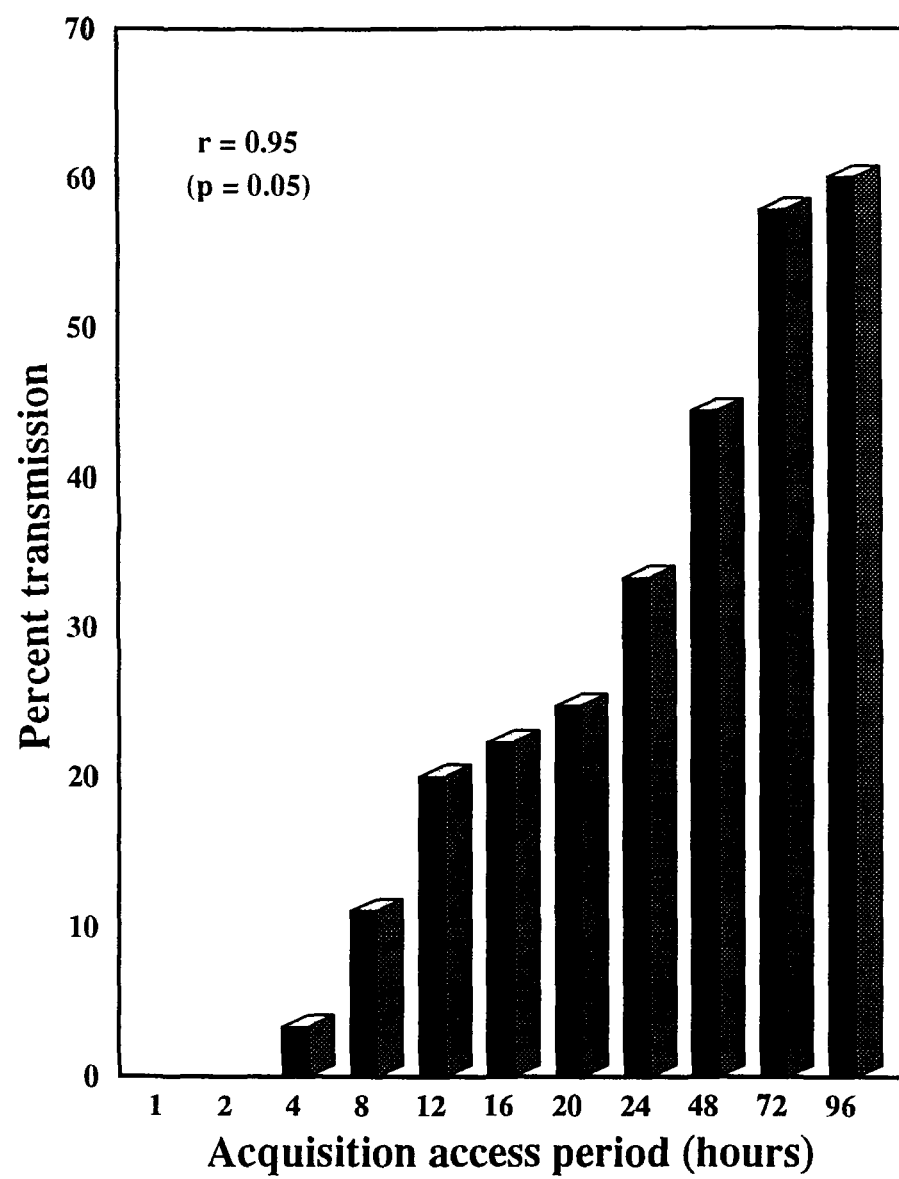


Figure 19. Acquisition access period of *Peregrinus maidis* on percent transmission of sorghum stripe virus

4.4.1.4 Incubation period of SStV in P. maidis

The minimum incubation period of virus in the vector and its relation to AAP was demonstrated. The results from Table 9 that the incubation period of virus in the vector in relation to the length of AAP on SStV infected plant varied from 10-12 days. The length of incubation period of virus in the vector was found to be 12,10,10,10, and 10 days with 24, 48, 72, 96 and 120 hrs AAP on the source plant respectively. The highest percent of 62.5% SStV infection was observed with 96 hrs AAP followed by two weeks of incubation period.

The data (Table 10) showed that the per cent transmission of SStV increased with increase in incubation period of virus in the vector. The transmission of 17.3% was observed with 4 days incubation and which increased to 62.6% with incubation period of 20 days (Fig. 20). The data also indicated positive correlation ($r = 0.94$) between incubation period and per cent SStV transmission.

4.4.1.5 Inoculation access period (IAP)

The results from Table 11 showed that the minimum inoculation access period was found to be 1 h with 8.9 per cent. As the IAP increases, the per cent transmission also increased giving 60 per cent transmission with 96 h of IAP (Fig. 21).

4.4.1.6 Persistence of SStV in P. maidis

The results (Table 12) showed that eight out of 20 insects

Table 9: Effect of different acquisition access period (AAP) on incubation of SStV in *P. maidis*^a.

AAP (hours)	Incubation period (days)									
	2	4	6	8	10	12	14	16	18	20
	Per cent infection ^b .									
24	0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	40.0	40.0
48	0	0.0	11.0	22.0	22.0	22.0	33.0	33.0	43.0	50.0
72	0	11.0	11.0	25.0	37.5	50.0	50.0	60.0	60.0	-
96	0	11.0	11.0	22.0	23.0	55.0	62.5	60.0	60.0	-
120	0	10.0	20.0	44.0	50.0	57.0	60.0	60.0	-	-

^a IAP 48 hrs, 2 insects/seedling used for inoculation

^b Per cent infection out of 10 seedlings.

Table 10: Effect of incubation period of SStV in P. maidis^a on transmission efficiency

Incubation period (days)	Plants ^b infected	Per cent ^c transmission
4	2.6	17.3
8	5.4	36.7
12	6.4	43.3
16	9.0	60.0
20	9.4	62.6
24	9.4	62.6

^a AAP 4 days, IAP 48 hrs, 2 insects/seedling used for inoculation

^b Plants infected out of 15 seedlings

^c Mean of three experiments

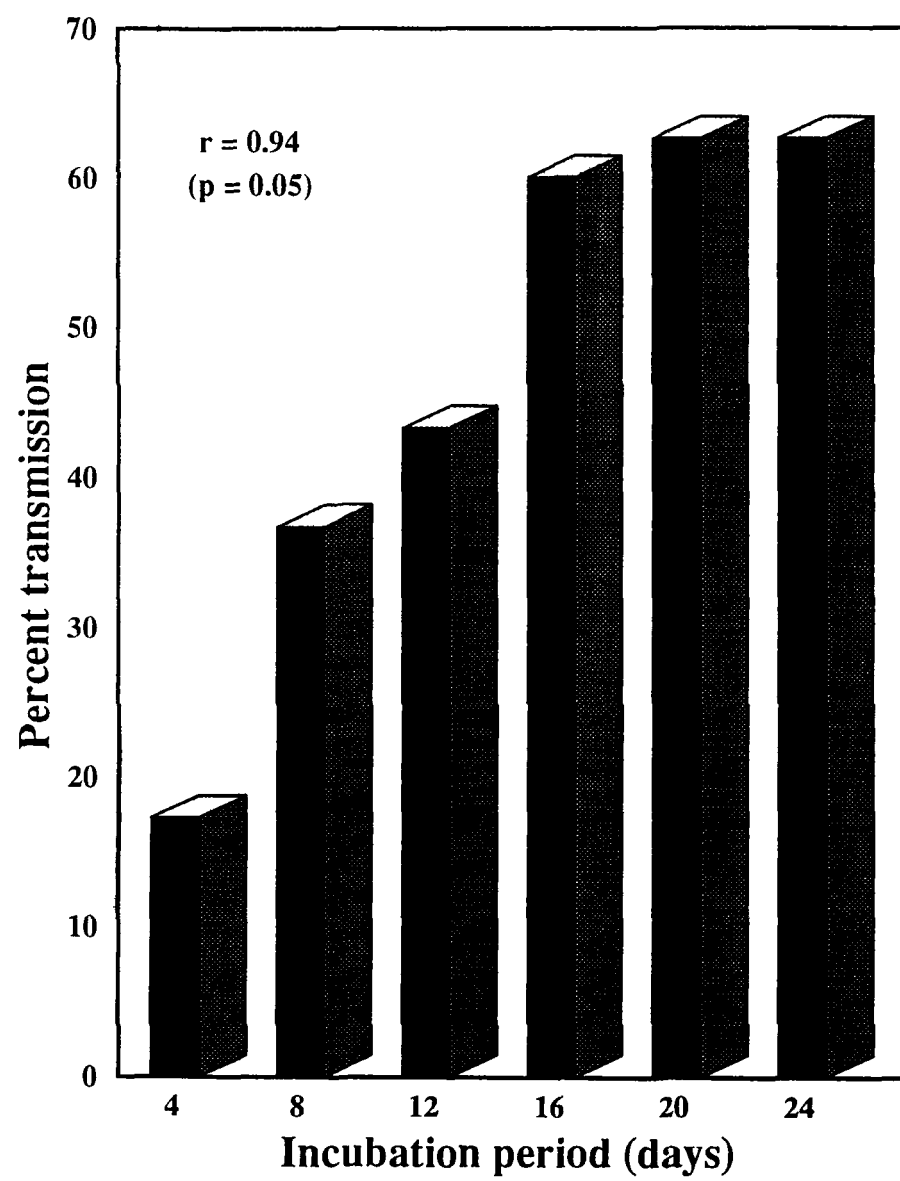


Figure 20. Incubation period of SStV in *Peregrinus maidis* on percent transmission.

Table 11: Effect of inoculation access period (IAP) by P. maidis^a on transmission of SStV.

IAP (hours)	Plants ^b infected	Per cent ^c transmission
1	1.3	8.9
2	2.6	17.8
4	2.6	17.8
8	3.4	22.7
12	3.7	24.7
16	4.3	28.9
20	4.7	31.3
24	5.6	37.3
48	7.7	51.3
72	8.6	57.3
96	9.0	60.0

a AAP 4 days, latent period 10 days

b Plants infected out of 15 seedlings

c Mean of three experiments

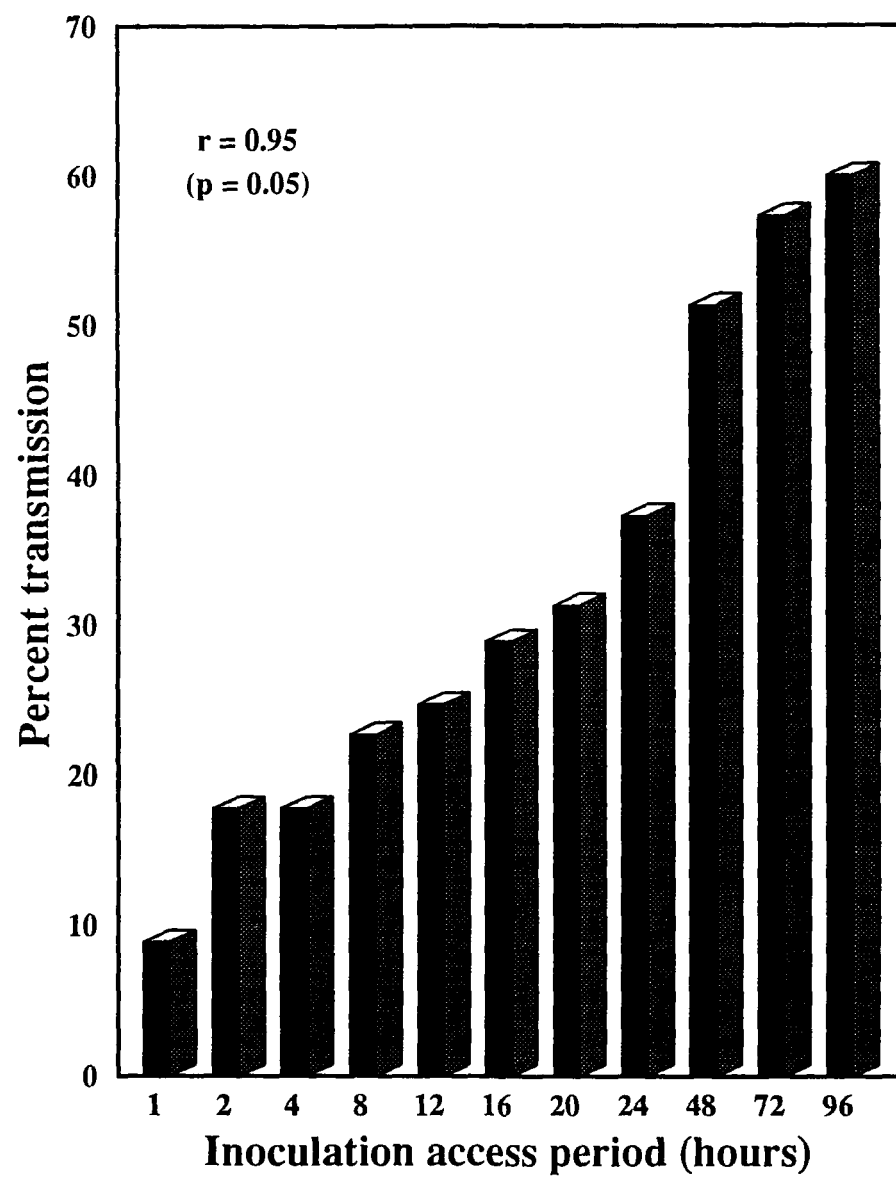


Figure 21. Inoculation access period of *Peregrinus maidis* on percent transmission of sorghum stripe virus

transmitted the virus until death (60 days) and the transmission was intermittent in six insects and continuous transmission was obtained only in two insect number 4 and 16 Table 12. The serial transmission tests indicates that the virus multiplied in the vector and the transmission was observed upto 60 days. Out of 442 test seedlings exposed to 20 viruliferous planthoppers, 157 (35.52%) seedlings took infection.

4.4.1.7 Transovarial transmission of SStV

Five hundred ninety five nymphs from 10 viruliferous female P. maidis were obtained immediately after they hatched out from the eggs laid in leaf midrib. Individual nymph was confined to healthy seedlings for 10 days. The results (Table 13) showed that out of 595 nymphs inoculated 18 nymphs transmitted SStV to sorghum seedlings. This shows that the virus was transovarially transmitted to the extent of 3.02 per cent through eggs laid by infective females.

4.4.1.8 Stages and forms of vector on SStV transmission

Healthy colonies of first to fourth instars and adult brachypterous and macropterous P. maidis were allowed 4 days on SStV infected plants separately followed by 10 days incubation period on healthy plants. Two insects/seedlings were confined on to 15 healthy seedling separately and allowed 48 h IAP. The results presented in Table 14 indicated that all the forms and stages transmitted the virus. When nymphs acquired the virus, the rate of transmission was more (63%) compared to adults (33.3%). Mac-

Table 12: Serial transmission and persistence of SSTV in Peregrinus maidis^a.

Insect number	Plant number/serial transfer																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1 ^b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

^a II and III third instar nymphs allowed 4 days AAP and 10 days IP.

^b Each insect allowed 48 hr IAP before transferring to next series of seedlings.

Table 13: Transovarial transmission of SStV through eggs of P. maidis

Viruliferous ^a female	Number of ^b nymphs	Plants inoculated	Plants infected	Per cent transmission
1	45	45	1	2.2
2	50	50	2	4.0
3	62	62	2	3.2
4	48	48	0	0.0
5	69	69	1	1.4
6	60	60	3	5.0
7	75	75	4	5.3
8	53	53	0	0.0
9	62	62	3	4.8
10	71	71	2	2.8
Total	595	595	18	3.02 ^c

^a Used for laying eggs after 4 days AAP and 10 days incubation

^b Eggs were removed from the plants on which viruliferous females were enclosed before emergence of nymphs and placed on healthy leaves. After hatching they were transferred to healthy seedlings for transmission.

^c Mean percent SStV transmission

ropterosus adults are more efficient in transmitting the virus (50%) than brachypterous forms (30.0%).

4.4.1.9 Efficiency of sex of *P. maidis* on SStV transmission

The results (Table 15) showed that adult female adults of both brachypterous and macropterous were found to be more efficient in transmitting SStV with 46.7 and 53.3 per cent transmission compared to male adults of brachypterous and macropterous adult males which showed 26.7 and 36.7 per cent respectively.

4.4.1.10 Effect of age of sorghum on SStV transmission

The results presented in Table 16 showed that plants get infected at all the growth stages. The SStV transmission was 62 per cent when inoculated at coleoptile stage compared to 46.6 per cent at 10th leaf stage. The percentage of transmission decreases with increase in age of plants. The age of the plant also prolonged the days required to express symptoms (Fig. 22). Incubation period in the plant was 8.1 days when inoculated at plumule stage, while it was 17.8 days when inoculated at 10 leaf stage.

4.4.2 Seed transmission

4.4.2.1 Detection of SStV in seed at different stages of seed development by PNC - ELISA

Samples were collected from SStV infected plants at various

Table 14: Effect of stage and forms of *P. maidis* on SStV transmission

Stage and forms ^a of insects	Plants ^b infected	Per cent ^c infection
First instar nymphs	9.5	63.3
2nd, 3rd and 4th instar nymphs	7.5	50.0
Adults	5.0	33.3
Brachypterous	4.5	30.0
Macropterous	7.5	50.0

^a Each stage and forms of insects were allowed 4 days AAP, 10 days incubation and 48 hrs IAP

^b Plants infected out of 15 seedlings inoculated

^c Means of three experiments

Table 15: Effect of sex of *P. maidis* on SStV transmission

Forms and sex ^a of insects	Plants ^b infected	Per cent ^c infection	Mean
Brachypterous			
Male	4.0	26.7	
Female	7.0	46.7	36.7
Macropterous			
Male	5.5	36.7	
Female	8.0	53.3	45.0

^a Each stage given 4 days AAP, 10 days incubation and 48 hrs IAP. One insect/seedlings used for inoculation

^b Plants infected out of 15 seedlings inoculated

^c Mean of two experiments.

Table 16: Effect of growth stages of sorghum on SStV infection

Growth stages	Age of plants (days)	Average No. of plants ^a infected	Aver. No. of Days to express symptoms	Per cent ^b . infection
Plumule	2	9.3	8.1	62.0
2-leaf	5	8.6	9.8	57.7
4-leaf	15	8.0	10.1	53.3
6-leaf	22	8.0	12.1	53.3
8-leaf	30	7.6	15.8	50.0
10-leaf	40	7.0	17.8	46.6

^a P. maidis was given 4 days AAP, 10 days incubation and 48 hours IAP, 3 insects per seedlings, average no. of plants infected out of 15 seedlings inoculated.

^b Mean of three experiments

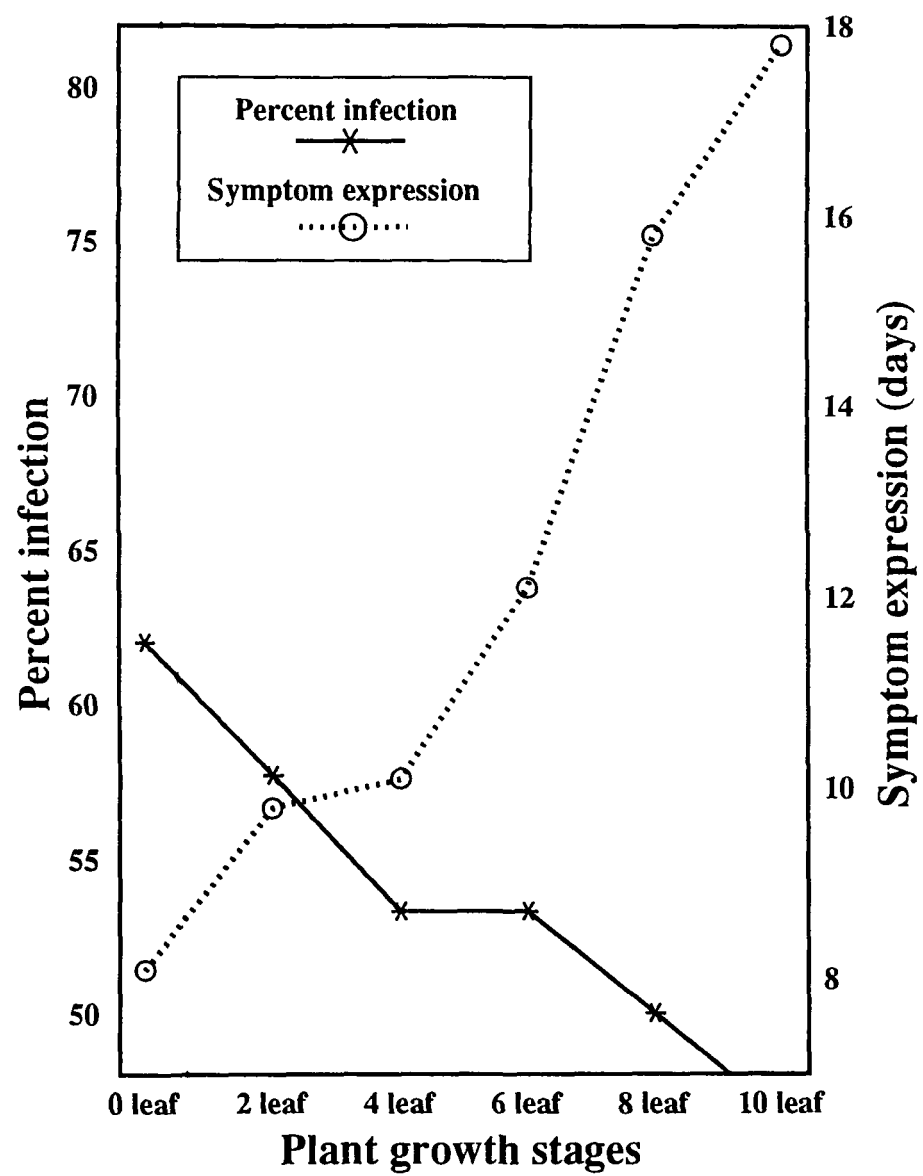


Figure 22. Effect of sorghum growth stages on percent infection and days to express SStV symptoms

stages of seed development, starting from pre-flowering to maturity and tested by ELISA for SStV presence. The data presented in the Table 17 showed the presence of SStV from pre-flowering to milky stage. The detection of SStV was 3 out of 5 samples at seed maturity and 2 out of 5 samples in dried seed. It is also observed from the Table 17 that SStV could be detected in glumes from all the stages of seed development including dried seed glumes.

4.4.2.2 Growing out test to find out SStV transmission from seed to plant.

Seeds were collected from naturally infected sorghum plants showing SStV symptoms on 2nd, 3rd and 4th leaves infected from top. The results indicated that out of 975 seedlings raised from seed collected from infected plants neither showed any infection nor the seedlings differed in appearance and growth when compared to seedlings raised from healthy seeds (Table 18). The seedlings raised from seeds of SStV infected plants reacted negatively to ELISA one month after emergence.

Seeds from infected heads were allowed to sprout for 24 h after pre-soaking in water for 3 h. Fifteen groups each of 10 sprouted seeds were tested by ELISA. Out of 15 samples tested, 9 samples showed positive reaction in ELISA, indicating the presence of SStV in sprouted seeds but the transmission was not observed when seedlings were grown from sprouted seeds.

Table 17: Detection of SStV by ELISA at different stages of seed development in infected sorghum plant (CSH-9)

Stages of seed ^a development		ELISA reactions ^b . Plant numbers				
		1	2	3	4	5
Inflorescence in boot leaf		+	+	+	+	+
Inflorescence after emergence		+	+	+	+	+
Flowering		+	+	+	+	+
Seed initiation stage		+	+	+	+	+
Milky stage:	Seed	+	+	+	+	+
	Glume	+	+	+	+	+
Seed maturity:	Seed	+	+	-	+	-
	Glume	+	+	+	+	+
Dried seed:	Seed	-	+	-	-	+
	Glume	+	+	+	+	+

^a Samples collected from 5 infected plants at each stage, each sample tested in duplicate wells, a group of five seeds/sample tested

^b ELISA reaction scored visually as positive (+) and negative (-)

Table 18: Growing out test for SStV transmission through seed to plant and reaction to ELISA

SStV ^a infected plants	Plant ^b number	Total seeds planted	Infected plants	ELISA ^c reaction	Sprouted ^d seeds	ELISA reaction
2 leaves	1	65	0	-	10	-
	2	65	0	-	10	-
	3	65	0	-	10	-
	4	65	0	-	10	+
	5	65	0	-	10	+
3 leaves	1	65	0	-	10	-
	2	65	0	-	10	+
	3	65	0	-	10	-
	4	65	0	-	10	+
	5	65	0	-	10	+
4 leaves	1	65	0	-	10	+
	2	65	0	-	10	+
	3	65	0	-	10	-
	4	65	0	-	10	+
	5	65	0	-	10	+

^a Seeds harvested from infected plants at 3 levels of SStV infection 2, 3 and 4 leaves infected from top

^b Five infected plants selected for each level of infection

^c ELISA reaction tested in duplicate wells one month after planting, reactions visually scored as positive (+) and negative (-)

^d Group of 10 sprouted seeds/sample used for ELISA test.

4.5 Epidemiology

4.5.1 Incidence of SStV and planthopper in main sorghum crop

The first field appearance of the disease was observed when the crop age was 20 days after emergence (Table 19). The incidence of 0.12% was observed when the crop was of 20 days old and increased upto 4.9% incidence on plants of 80 days. The vector population was 0.13 per plant at 20 days after planting and reached maximum of 2.4 per plant at 60 days. The vector population decreased to 2.1 per plant after flowering, whereas the SStV symptom expression increased as the age of the crop increased (Fig. 23a).

4.5.2 Incidence of SStV and planthopper in ratoon sorghum

The results from Table 20 showed that the number of SStV infected plants was 51 (7.96%) during first 20 days after sprouting of ratoon crop. The number of infected plants increased with a maximum of 186 plants (29.02%) when the crop was 80 days old. It was also observed (Fig 23b) that the vector populations increased to 8.6 insects per plant when the age of ratoon crop was 60 days and later declined to 4.2 per plant at 80 days. The data indicate that the incidence of SStV in ratoon crop was 29.02 per cent when compared to 4.9 per cent incidence in main sorghum crop. Similarly the vector population of 4.2 per plant was observed in ratoon as compared to 2.1 per plant in main sorghum crop.

Table 19: Incidence of SStV and population of planthopper (*P. maidis*) at different intervals in main sorghum crop during rabi 1991 at MRS, UAS, Bangalore.

Days after ^a planting	Infected ^b plants	Per cent infection	Planthoppers ^c . per plant
20	1	0.12	0.13
40	8	1.01	1.03
60	21	2.64	2.40
80	39	4.90	2.10

^a Date of planting 10/8/91

^b Number of infected plants out of 795 plants

^c Planthopper count/plant taken from top four leaf whorls in thirty randomly selected plants

Table 20: Incidence of SStV and population of planthopper (*P. maidis*) in ratoon sorghum at different intervals during summer 1992 at MRS, UAS, Bangalore.

Days after ^a harvest	Infected ^b plants	Per cent infection	Planthoppers ^c . per plant
20	51	7.95	2.80
40	84	13.10	4.06
60	129	20.12	8.60
80	186	29.02	4.23

^a Date of harvest 14/12/91

^b Number of infected plants out of 641 plants

^c Planthopper count/plant taken from top four leaf whorls in thirty randomly selected plants

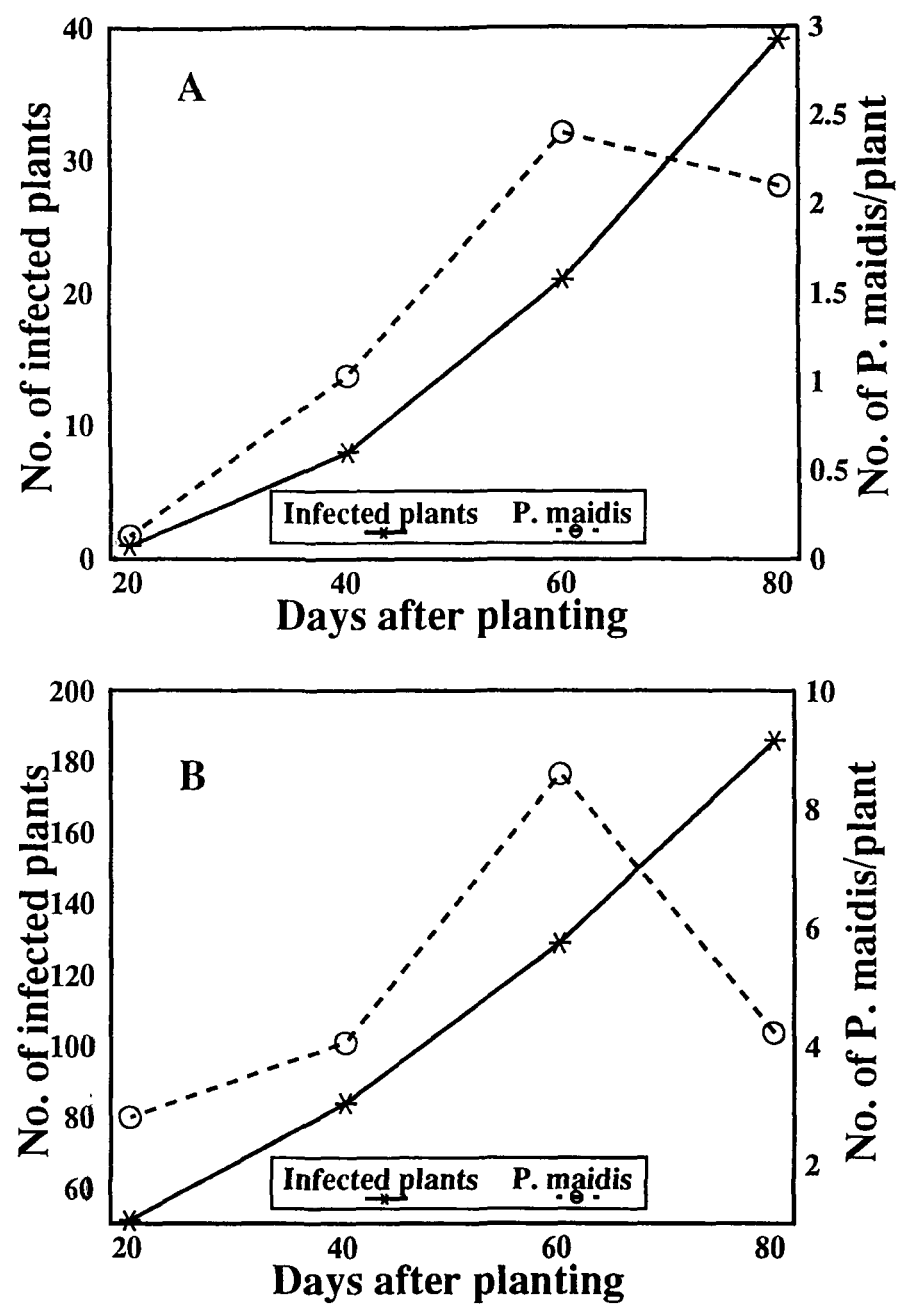


Figure 23. Incidence of SStV and *Peregrinus maidis* population in main (A), ratoon (B) sorghum crop in Rabi 1991

4.5.3 SStV symptom expression during main sorghum cropping season.

Symptom expression was assessed on main plant, nodal and basal tillers and the results are presented in Table 21. The maximum symptom expression was observed on nodal tillers upto 5.4 per cent when compared to 4.41 and 2.53 per cent on main plants and basal tillers respectively. The SStV symptom expression on internodal and basal tillers are presented in Fig. 24 and 25.

During the field observations it was noticed that many plants infected at later stages could not express symptoms either on main plant, internodal or basal tillers. Plants showing stunted growth, short peduncle and acute apical bending of earhead (Fig. 15) were assessed in ratoon sprouting. The data presented in Table 22 show that out of 123 plants labelled as suspected to be infected, 70 plants (57.48%) expressed characteristic SStV symptoms in ratoon sorghum crop (20 days after harvesting of main crop).

4.5.4 Influence of overlap sorghum cropping on incidence of SStV and planthopper populations.

Field experiment was conducted to know the effect of continuous and overlap cropping pattern of sorghum on incidence of SStV and planthopper population. The data on incidence of SStV and planthopper population on main, ratoon and overlap main crop are presented in Table 23. The results indicate that the incidence of 4.79 percent, 29.3 per cent and 32 per cent were

Table 21: Symptom expression of SStV in sorghum crop under field conditions before harvest of main crop

Symptom Expression	Number of infected plants ^b				Per cent infection
	Plot 1 ^a	2	3	Mean	
Main plant ^c	11	12	12	11.7	4.41
Nodal tillers ^d	19	14	10	14.3	5.40
Basal tillers ^e	4	8	8	6.7	2.53
Total plants	227	223	345	265.0	-

^a Each plot measuring 12 m x 2 m

^b Infected plant counts taken 2 weeks before harvest

^c Symptom expressed on main plant

^d Symptom expressed on internodal tillers

^e Symptom expressed on basal tillers but no symptoms expression on main plant.

Table 22: Expression of SStV symptoms in ratoon sorghum which are masked in main sorghum crop under field conditions

Symptoms	Number of infected plants				Per cent infection
	Plot 1	2	3	Mean	
Suspected plants ^a . in main crop	41	50	32	41	15.47
Symptoms appeared ^b . in ratoon crop	28	27	15	23	57.48
Total plants	227	223	345	265	-

^a Plants suspected to be infected by SStV based on short peduncle and apical bending of earhead

^b Visible symptom expression in ratoon sorghum recorded 20 days after harvest of main crop

Fig. 24. Symptoms expression on nodal tillers of sorghum plant due to late infection of SStV

Fig. 25. Basal tillers of sorghum plant showing symptoms of SStV



Fig. 24



Fig. 25

Table 23: Influence of successive/overlap cropping of sorghum on incidence of SSTV and planthopper (*P. maidis*) populations

Days after planting	Main crop ^a		Ratoon crop		Overlapping				
	Infected plants	Per cent infection /plant	Infected plants	Per cent infection /plant	Infected plants	Per cent infection /plant			
20	1	0.12	0.13	51	7.96	2.80	3	0.77	2.71
40	7	0.88	1.00	33	5.15	4.06	35	9.04	4.53
60	13	1.63	2.40	45	7.02	8.60	54	13.95	9.20
80	18	2.26	2.10	57	9.17	4.23	32	8.27	1.81
Total	39	4.79	6.03	186	29.30	19.69	124	32.03	18.24
Mean	9.75	1.19	1.57	46.5	7.32	4.92	31.0	8.00	4.56

a Date of planting; main crop - Aug. 91, ratoon crop - Jan. 92, main crop - May 92

b Total plant populations; main crop -795, ratoon crop - 641, main crop - 387

c $\chi^2 = 10.19$

d $\chi^2 = 4.02$

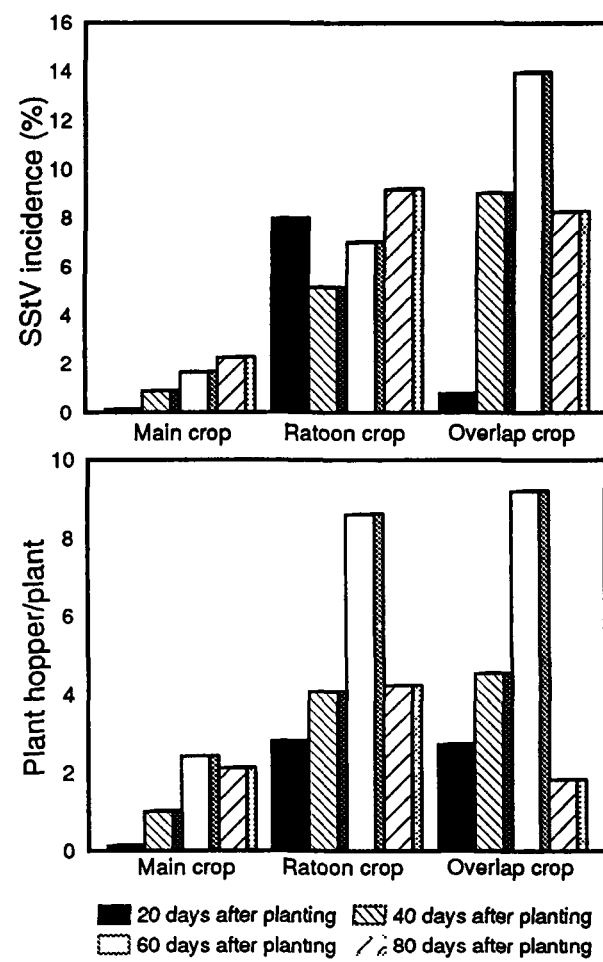


Figure 26. Influence of successive sorghum cropping on incidence of SStV and plant hopper populations in main, ratoon and overlap crop

observed in main crop, ratoon crop and overlap main crop respectively. Similarly the planthopper populations of 1.57, 4.92 and 4.56 per plant were observed on main crop, ratoon and overlapping crop respectively. The data indicate the influence of previous sorghum crop on SStV incidence ($x^2 = 10.19$) and planthopper population ($x^2 = 4.02$). It was also found (Fig. 26) that there was increasing incidence of SStV and planthopper population on overlap sorghum crop in comparison with ratoon. The present investigations showed the influence of previous crop on perpetuation of SStV and planthopper population build up from one season to other seasons.

4.5.5 Incidence and spread of SStV at various growth stages of sorghum under field conditions.

A field experiment was laid out to study the incidence of SStV and spread of the disease at various growth intervals during rabi cropping season 1991 at MRS, UAS, Bangalore. The results presented in Table 24 showed the first appearance of disease on 30th day after planting. There was cumulative increase in the incidence of disease at every 15 days interval upto 120 days and reached the incidence of 4.47 per cent during the entire cropping period. The maximum increase of disease was observed between 60 and 75 days after planting, later stages the number of infected plants reduced. The maximum planthoppers population reached at 60 days after planting and declined as the crop reached flowering stage. The increasing trend of SStV disease at 30, 45, 60, 75, 90 and 105 days intervals of crop age is presented in Fig. 28.

Table 24: Incidence and pattern of SStV spread and plant-hopper population at different growth stages of sorghum crop at MRS, UAS, Bangalore during rabi 1991.

Days after ^a planting	Infected ^b plants	Per cent infection	Planthopper ^c . /plant
30	1	0.05	1.03
45	5	0.26	2.10
60	22	1.16	2.80
75	54	2.84	1.50
90	70	3.37	1.20
105	78	4.10	0.73
120	85	4.47	0.40

^a Date of planting 10/8/91

^b Infected plants out of 1900 plants (16 m x 16 m plot)

^c Planthopper count from top four whorls of 30 randomly selected plants in the field

Table 25: Mean monthly rainfall, temperature and relative humidity from Jun 1991 to Aug 1992 at MRS, UAS, Hebbal, Bangalore.

Months	Rainfall (mm)	Temperature (°C)		Relative humidity(%)	
		Max.	Min.	Max.	Min.
Jun 91	154.5 (9)	29.2	21.0	91.0	67.0
Jul 91	47.7 (5)	28.1	19.8	90.0	64.0
Aug 91	158.0 (14)	27.4	19.4	93.0	67.0
Sept 91	149.0 (7)	29.2	19.7	92.0	60.0
Oct 91	377.0 (11)	27.8	19.0	94.0	66.0
Nov 91	182.3 (4)	25.7	17.3	93.0	63.0
Dec 91	-	26.1	14.6	92.0	50.0
Jan 92	-	26.4	12.1	92.0	38.0
Feb 92	-	30.3	26.4	91.0	43.0
Mar 92	-	33.1	14.1	80.0	25.0
Apr 92	2.8 (2)	34.0	19.9	81.0	32.0
May 92	142.9 (9)	33.2	21.1	85.0	45.0
Jun 92	154.8 (8)	29.6	20.3	91.0	61.0
Jul 92	118.7 (5)	28.3	19.2	91.0	63.0
Aug 92	62.5 (9)	28.3	19.6	92.0	61.0
Sept 92	155.7 (8)	28.6	19.3	92.0	61.0
Total	1705.9 (91)	465.4	292.8	1440.0	866.0
Mean	106.6	29.1	18.3	90.0	54.1

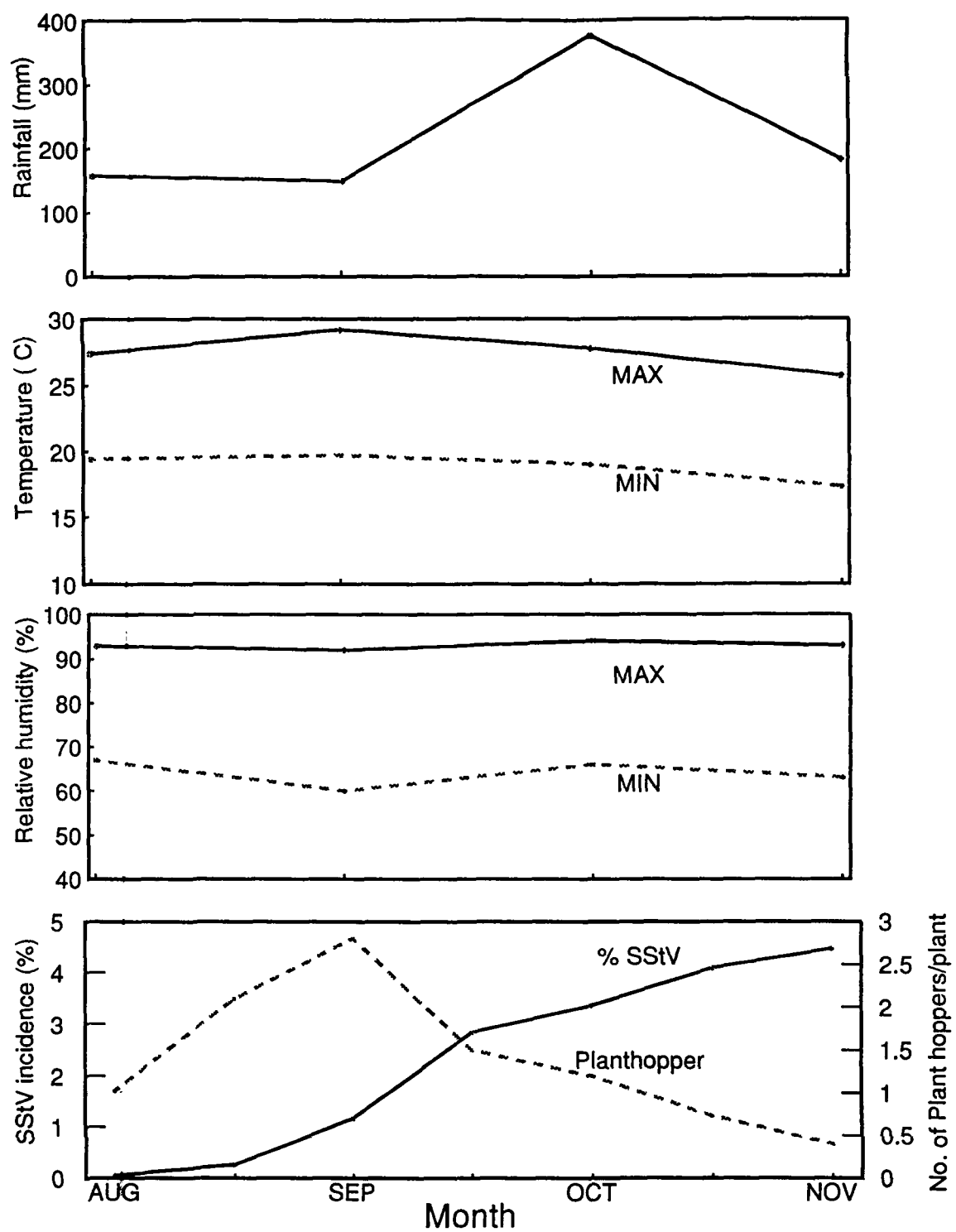


Figure 27. Incidence of SStV and plant hopper population in relation to weather parameters during Rabi 1991.

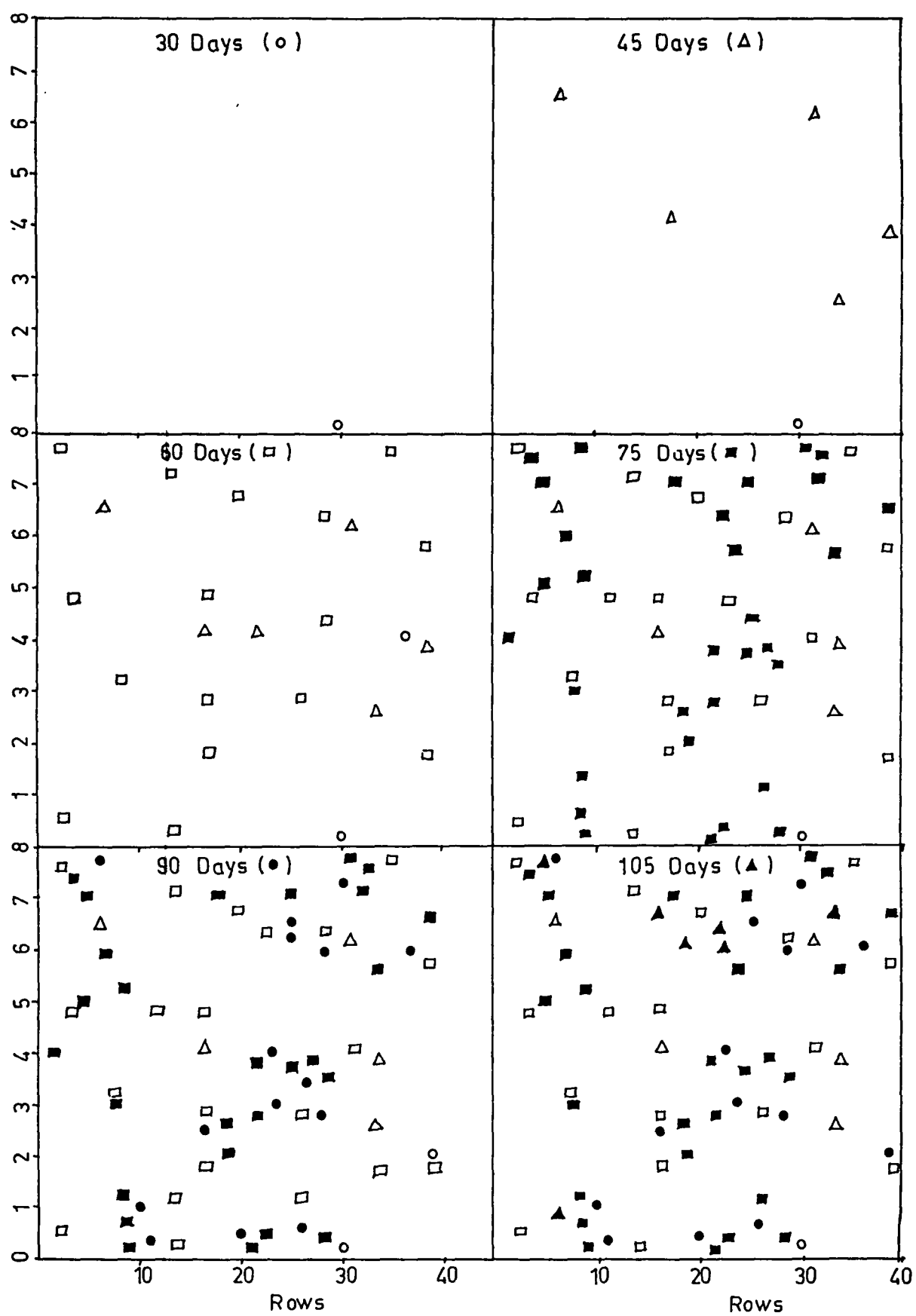


Fig. 28. Sorghum stripe virus disease increase at different growth intervals (days) during rabi 1991 cropping season

4.5.6 SStV and planthopper incidence to weather parameters

The weather parameters like rainfall, temperature and relative humidity for the rabi cropping period (Aug. 91 to Dec. 91) in Table 25. compared with SStV and planthopper incidence. The results (Fig. 27) of planthopper in relation to weather data showed that moderate rainfall coupled with temperature ranging from 25 to 30°C and high relative humidity (>90%) found congenial for multiplication of the vector. With the increase in age of the plants there is decrease in incidence of infected plants was noticed.

4.5.7 Distribution pattern of SStV disease

The distribution pattern of SStV under field conditions during rabi 1991 was recorded at the time of flowering (Fig. 29). The analysis of mean ($\bar{u}$), variance (s^2), measures or extent of dispersion (k) and green index (GI) which measures the degree of clumping for SStV distribution is presented in Table 26. The data showed that the variance (s^2) ranging from 0.65 to 1.48 which is more than the mean in all the six samples, indicated the clumping pattern of distribution. The smaller the values of K (measures the extent of aggregation) and green index (degree of clumping) the higher the extent of aggregation and lower degree of clumping. Since the maximum value of 1 is for high degree of clumping, '0' value indicates the random type of distribution (Ludwig and Reynolds, 1988).

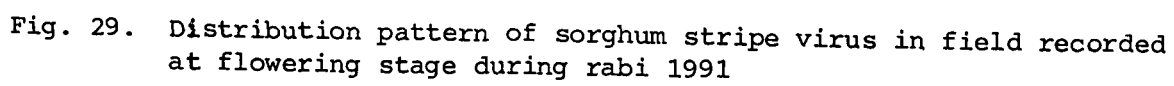


Fig. 29. Distribution pattern of sorghum stripe virus in field recorded at flowering stage during rabi 1991

Table 26: Mean, variance, measures of dispersion and green index for SStV distribution pattern under field conditions during 1991 at MRS, UAS, Bangalore.

Sample No. ^a	Number of infected plants	Mean X	Variance S ²	K	GI
1	24	0.061	1.48	0.0027	0.06
2	16	0.040	0.65	0.0026	0.04
3	20	0.048	0.95	0.0025	0.05
4	17	0.041	0.69	0.0025	0.04
5	18	0.042	0.72	0.0026	0.04
6	22	0.044	0.76	0.0027	0.04

^a Each sample represents 10 rows with 400 plants/row

X = Mean number of plants infected per row

S² = Variance

K = Measure or extent of agregation (smaller the value greater the agregation)

GI = Green index : is a measure of degree of clumping. GI varies from zero (Random) and one (maximum clumping).

4.5.8 Transmission of SStV by field population of P. maidis

Field populations of P. maidis collected directly from the field were tested in greenhouse for SStV transmission assay. The results (Table 27) showed that when single insect was used there was 6 per cent transmission with planthoppers from uninfected plants for inoculation, where as 54.7 per cent transmission was obtained from planthoppers collected from SStV infected plants. Mass inoculation of sorghum seedlings by group of insects from infected plants gave 64.7 per cent transmission and it was 9.2 per cent insects from uninfected plants.

The ELISA test was successfully used to detect the virus in field population of planthoppers. The data presented in Table 28 indicate the detection of SStV in 8.3 per cent population of first instar nymphs, whereas 25 and 33% detection was observed from male and female populations collected from the field. This indicates that ELISA test could be employed in monitoring the field populations of planthoppers carrying the virus.

4.5.9 Survival of SStV in stored infected leaves

An experiment was conducted to know the effect of survival of SStV in infected sorghum leaves under stored conditions at -10°C and $5-8^{\circ}\text{C}$ and tested the samples every month by ELISA over a period of one year. The results (Table 29) indicated that the virus could be detected upto one year from the infected leaf samples stored at -10°C . Where as the samples stored at $5-8^{\circ}\text{C}$ failed to react in ELISA after five months.

Table 27: Testing field populations of *P. maidis* for transmission of SStV

Source of insects	Total seedlings	Number infected	Per cent transmission
Infected ^a . plants	75	41.0	54.7
Uninfected ^a . plants	75	4.5	6.0
Infected ^b . plants	200	129.5	64.7
Uninfected ^b . plants	200	18.5	9.2

^a Individual seedlings inoculated, one insect/seedling

^b Group of seedlings inoculated at the rate of two insects/seedling

Table 28: Detection of SStV in field populations of (*P. maidis*) by PNC-ELISA.

Stage of ^a insects	Number of ^b insects	ELISA ^c reaction	Per cent detection
1st instar	12	1	8.3
2nd and 3rd instar	12	3	25.0
Adults:			
Male	12	3	25.0
Female	12	4	33.3

^a *P. maidis* collected from field with 10% SStV infection

^b Each insect tested in duplicate wells

^c ELISA reaction scored visually as positive (+) or negative (-)

Table 29: Survival of SStV in infected leaves stored at -10°C and 5-8°C and its detection by ELISA.

Date of sampling	ELISA reaction ^a	
	-10°C	5-8°C
1.9.91	+	+
1.10.91	+	+
1.11.91	+	+
1.12.91	+	+
1.1.92	+	+
1.2.92	+	-
1.3.92	+	-
1.4.92	+	-
1.5.92	+	-
1.6.92	+	-
1.7.92	+	-
1.8.92	+	-
1.9.92	+	-

^a ELISA reactions scored visually as positive (+) or negative (-)

^b Samples stored in freezer

^c Samples stored in refrigerator

4.5.10 Disease cycle of SStV

Sorghum stripe virus of sorghum is transmitted by the delphacid planthopper (P. maidis). The means of survival of virus and the vector transmitting SStV in absence of the main host are the most critical stages in the disease cycle. The events that occur in the epidemiology of sorghum stripe disease on sorghum are represented in the diagram (Fig. 30). The wild relative of sorghum species johnsongrass (Sorghum halepense) a perinneal host served as primary source of SStV inoculum in the absence of main host. Towards the beginning of rainy season the rhizomes of johnsongrass survived on bunds, irrigation canals and symptoms expressed on these sprouted seedlings. A few planthopper population survived on plants from ratoon stubbles and stems of johnsongrass multiplied with the sprouting of johnsongrass and the young nymphs fed on SStV infected johnsongrass leaves. The adult macropterous carrying the virus moved to farther places in search of suitable host (sorghum). The viruliferous adults inoculate the sorghum and form foci of SStV infection.

The planthopper laid eggs on the same plant and produced new generation and the young nymphs fed on infected plants. The macropterous viruliferous adults initiate spread of disease in the entire field, whereas brachypterous individuals moved to neighbouring plants/fields and cause newer infection. Thus the secondary spread within the field was initiated from the foci of the SStV infected plant. Continuous cultivation and distribution of susceptible sorghum variety over larger area helps in build up

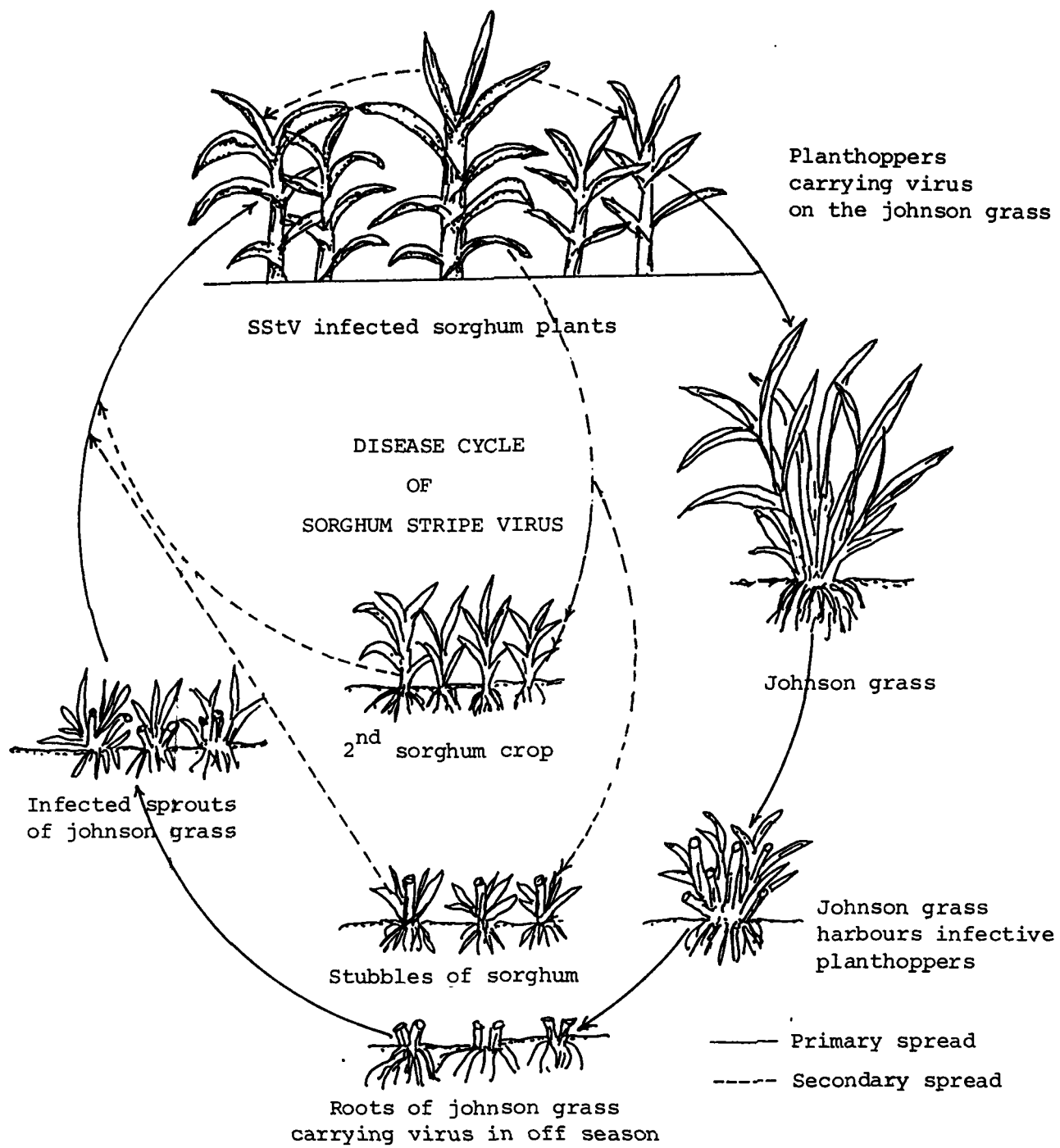


Fig. 30. Role of johnson grass (*Sorghum halepense*) in perpetuation and spread of sorghum stripe virus disease

of inoculum and multiplication of the vector.

The SStV carrying planthopper from the infected plants during the kharif season after flowering the viruliferous macropterous planthoppers moved to distant or adjacent crop planted during rabi season. The viruliferous planthopper survived in stubbles, ratoon sprouts or johnsongrass present on field bunds and irrigation canals. The summer crop immediately after rabi in irrigated tracts helps in build up of virus carrying planthoppers and further spread of the disease. The johnsongrass in the surrounding fields and the stubbles of summer sorghum crop also harbours the virus and planthopper which served as source of inoculum for the fresh sorghum crop in rainy season. Thus the SStV and its vector P. maidis survived throughout the year.

4.6 Host range of SStV and planthopper

4.6.1 Cultivated host plants

The host range of sorghum stripe virus was tested on 11 cultivated graminaceous host plants which include maize, rice, bajra, wheat, barley, ragi, sugarcane, navane, little millet, barnyard millet and kodo millet. Fifteen to twenty seedlings raised from each cultivar in polythene bags were inoculated by using adult viruliferous P. maidis. The data presented (Table 30) suggests that only wheat showed typical chlorotic stripe symptoms (Fig. 31) in 10 days after inoculation and infected

Table 30: Reaction of cultivated graminaceous crop plants to sorghum stripe virus.

Test plants	Common name	Cultivar	Plants ^a inoculated	Plants infected	Per cent infection	Survival ^b of vector	ELISA ^c . reaction
<u>Zea mays</u>	Maize	Amber	15	-	-	6	-
		Ageti	15	-	-	6	-
		Deccan-103	15	-	-	13	-
		Ganga-5	15	-	-	12	-
		Ganga-11	15	2	13.3	12	-
		Madhuri	15	-	-	8	-
		Navjot	15	-	-	13	-
		Sartaz	15	1	6	14	-
<u>Oryza sativa</u>	Rice	IR-20	12	-	-	0	-
		IR-54	15	-	-	1	-
		Mukti	14	-	-	1	-
		Mahavir	15	-	-	0	-
<u>Pennisetum americanum</u>	Bajra	IPC-94	19	-	-	10	-
		IPC-107	21	-	-	8	-
		IPC-388	17	-	-	12	-
		IPC-501	20	-	-	6	-
		IPC-736	16	-	-	10	-
<u>Setaria italica</u>	Navane	TNAU-83	16	-	-	0	-
		GPUS-2	16	-	-	0	-
		SIC-19	16	-	-	0	-

(Contd -.....)

Test plants	Common name	Cultivar	Plants ^a inoculated	Plants infected	Per cent infection	Survival ^b of vector	ELISA ^c reaction
<u>Triticum aestivum</u>	Wheat	Bijga yellow	15	3	20	13	+
		Raj-1555	15	2	13.3	10	+
		DH-39	15	-	-	13	-
		Local red	12	-	-	12	-
		Kiran	14	-	-	6	-
		HD-2189	15	-	-	14	-
<u>Hordeum vulgare</u>	Barley	NI-5439	15	-	-	9	-
		RD-31	15	-	-	13	-
		Ratna	15	-	-	14	-
		Azad	20	-	-	8	-
		Karan-16	16	-	-	8	-
		Kedar	12	-	-	4	-
<u>Eleusine coracana</u>	Ragi	Jyoti	18	-	-	12	-
		VL-137	16	-	-	0	-
		VL-149	16	-	-	0	-
		VR-584	16	-	-	0	-
		BAU-2	16	-	-	0	-
		GPU-25	16	-	-	0	-
<u>Saccharum officinarum</u>	Sugarcane	Co-419	12	-	-	0	-
		Co-7804	9	-	-	0	-
		Co-62175	10	-	-	2	-
		KHS-3296	16	-	-	2	-

(Contd.....)

Test plants	Common name	Cultivar	Plants ^a inoculated	Plants infected	Per cent infection	Survival ^b of vector	ELISA ^c reaction
<u>Panicum miliare</u>	Little millet	Co-2 BAU-4 SLTPO	16 16 16	- - -	- - -	0 0 0	- - -
<u>Echinochloa fumentacea</u>	Barnyard millet	KE-33 VL-45 VL-47 TNAU-83 REF-74-1	16 16 16 16 16	- - - - -	- - - - -	0 0 0 0 0	- - - - -
<u>Paspalum scrobiculatum</u>	Kodo millet	KMV-8 KMV-20 GPUK-5 IPS-147 PSC-1	20 20 20 20 20	- - - - -	- - - - -	2 3 0 5 2	- - - - -
<u>Sorghum bicolor</u>	Sorghum	CSH-9	20	18	90	34	+

II and III instar nymphs of P. maidis allowed four days AAP, 10 days IP and 72 hr IAP on group of seedlings in each cultivar.

^a Group of seedlings (3-4 leaf stage) were inoculated with 2 insects/seedlings.

^b Survival of planthopper counted at the end of 72 hr IAP

^c ELISA reaction scored visually as positive (+), or negative (-).

Fig. 31. Wheat (Triticum aestivum) leaves showing typical SStV symptoms



Fig. 31

leaves reacted positively to SStV antiserum in ELISA test. The rest of the plants failed to produce any symptoms and reacted negatively to SStV antiserum when tested one month after inoculations.

4.6.2 Fodder grasses

In addition to the cultivated hosts, 37 fodder grass species/varieties maintained for 5-6 years at MRS, Hebbal were tested for natural infection by SStV. The leaf samples which showed stunted growth yellowing, mosaic, stripe and streak symptoms were collected from fodder grasses and tested for SStV in ELISA. Excepting johnsongrass and sorghum, none of the suspected symptom types reacted positively in ELISA test (Table 31). Artificial inoculations of 20 fodder grasses by adult viruliferous *P. maidis* failed to show SStV symptoms except in johnsongrass (Table 32) where characteristic SStV symptoms appeared on leaves (Fig. 32) 10-15 days after inoculation.

4.6.3 Weed grasses

Sixteen weed grasses which are common in and around sorghum field were tested. The suspected symptoms showing leaves of *Panicum maximum*, *Cynodon dactylon*, *Digitaria ciliaris*, *Pennisetum purpureum* and *Dactyloctenium aegyptium* failed to react with SStV antiserum when tested by ELISA. 15-20 seedlings were raised and artificially inoculated using adult viruliferous *P. maidis*. The data presented (Table 33) showed that only johnsongrass expressed SStV symptoms and reacted positively in ELISA test. All the weed

Table 31: Reactions of suspected symptoms on fodder grasses collected from field to ELISA.

Fodder grasses*	Reaction of ELISA	Planthopper colonization
Napier thin	-	-
CO-1	-	-
Majjige	-	-
Green panicum (mutant)	-	-
Nandi setaria	-	-
<u>Paspalum notatum</u>	-	-
<u>Paspalum bryan</u>	-	-
<u>Setaria sp.</u>	-	-
Green panicum	-	-
Paragrass	-	-
Pusa napier	-	-
Kamadenu selection	-	-
Giant napier	-	-
Signal	-	-
Australian ragi	-	-
Anjan (IGFRS)	-	-
Arundamella	-	-
Blue panicum	-	-
Kumbu napier	-	-
Johnson grass	+	+
Rhodes (mutant)	-	-
Rhodes local	-	-
Dhallis	-	-
Guinea riverside	-	-
NB-17	-	-
BH-18	-	-
BN-2	-	-
BH-2	-	-
BH-12	-	-
H-2	-	-
BH-8	-	-
NB-5	-	-
NB-21	-	-
CN-2	-	-
Elephant grass	-	-
Weeping love grass	-	-
Sorghum	+	+

* Leaf samples of fodder grasses showing mosaic, stunted, stripe and streak symptoms collected for ELISA testing maintained in the field by Fodder Research Scheme for six years at MRS, UAS, Bangalore.

Table 32: Reaction of fodder grasses to sorghum stripe virus and to ELISA test.

Test plants	Plants ^a inoculated	Plants infected	Per cent infection	Survival ^b of vector	ELISA ^c reacti
Blue panicum	15	0	0	0	-
BH-8	20	0	0	0	-
CO-1	25	0	0	0	-
Dhallis	20	0	0	0	-
Elephant grass	25	0	0	0	-
Green panicum	19	0	0	0	-
Guinea grass	25	0	0	0	-
Guinea riverside	20	0	0	0	-
Johnson grass	20	6	30	24	+
Kamadhenu nepier	20	0	0	0	-
NB-21	20	0	0	0	-
Nepier thin	15	0	0	0	-
Nepier giant	18	0	0	0	-
Nepier pusa	20	0	0	0	-
Para grass	15	0	0	0	-
Pasphalum (Bryan)	20	0	0	0	-
Rhodes	20	0	0	0	-
Australian ragi	20	0	0	0	-
Setaria	20	0	0	0	-
Signal	20	0	0	0	-
Sorghum CSH-9	25	20	80	36	+

II and III instar nymphs of *P. maidis* allowed four days AAP, 10 days IP and 72 hr IAP on group of seedlings in each cultivar.

^a Group of seedlings (3-4 leaf stage) were inoculated with 2 insects/seedlings.

^b Survival of planthopper counted at the end of 72 hr IAP

^c ELISA reaction scored visually as positive (+), or negative (-).

Table 33: Reaction of weed grasses to sorghum stripe virus and to ELISA test.

Test plants	Plants ^a inoculated	Plants infected	Per cent infection	Survival ^b of vector	ELISA ^c . reactio
<u>Bracharia ramosa</u>	24	0	0	2	-
<u>Cyperus rotundus</u>	16	0	0	3	-
<u>Cynodon dactylon</u>	14	0	0	0	-
<u>Chloris barbata</u>	16	0	0	3	-
<u>Digitaria ciliaris</u>	20	0	0	8	-
<u>Dactyloctenium aegyptium</u>	25	0	0	25	-
<u>Echinochloa colona</u>	13	0	0	3	-
<u>Eleusine indica</u>	20	0	0	12	-
<u>Enteropogon monostachys</u>	20	0	0	4	-
<u>Eragrostis tenuifolia</u>	20	0	0	3	-
<u>Panicum repens</u>	20	0	0	6	-
<u>Panicum maximum</u>	26	0	0	6	-
<u>Rhytelyctrum repens</u>	18	0	0	8	-
<u>Themba triandra</u>	18	0	0	2	-
<u>Sorghum halepense</u>	20	6	30	30	+
Sorghum (CSH-9)	20	16	80	36	+

II and III instar nymphs of P. maidis allowed four days AAP, 10 days IP and 72 hr IAP on group of seedlings in each cultivar.

^a Group of seedlings (3-4 leaf stage) were inoculated with 2 insects/seedlings.

^b Survival of planthopper counted at the end of 72 hr IAP

^c ELISA reaction scored visually as positive (+), or negative (-).

grasses tested failed to express symptoms and reacted negatively to SStV antiserum in ELISA test.

4.6.4 Host range of planthoppers

Several fodder and weed grasses were observed for natural colonization of P. maidis in and around sorghum field at MRS, UAS, Bangalore. It was found that planthopper colonized (Fig. 33) and multiplied on johnsongrass but not on any other grass. During artificial inoculation the survival of P. maidis was recorded at the end of 72 hrs feeding period. The observation (Table 30 to 33) showed, that only on johnsongrass, maximum planthoppers survived. Whereas in maize, wheat and barley cultivars, 35.6, 32.8 and 23.9 per cent of planthoppers survived at the end of 72 hrs of IAP. On other plants, there was complete death of planthoppers within 72 hrs.

4.7 Effect of SStV on sorghum plant growth and grain yield

4.7.1 Effect of SStV on chlorophyll and NPK contents and growth parameters.

The data presented in Table 34 showed that SStV infection at seedlings stage severely affected the growth (Fig. 36) and finally death of seedlings. The data collected one month after inoculation indicates that SStV infection in sorghum seedlings reduced the plant height (62.55%), leaf number (22.05%), ^{average} leaf area (45.45%), fresh shoot weight (87.25%) and dry weight (91.89%) and loss in chlorophyll content (46.98%) respectively in comparison with uninoculated healthy seedlings. Nitrogen con-

Fig. 32a. Johnsongrass (Sorghum halepense) leaves showing SStV symptoms

Fig. 32b. Johnsongrass (Sorghum halepense) sprouted leaves from ratton showing SStV symptoms

Fig. 33. Colonization of Peregrinus maidis on johnsongrass (Sorghum halepense).

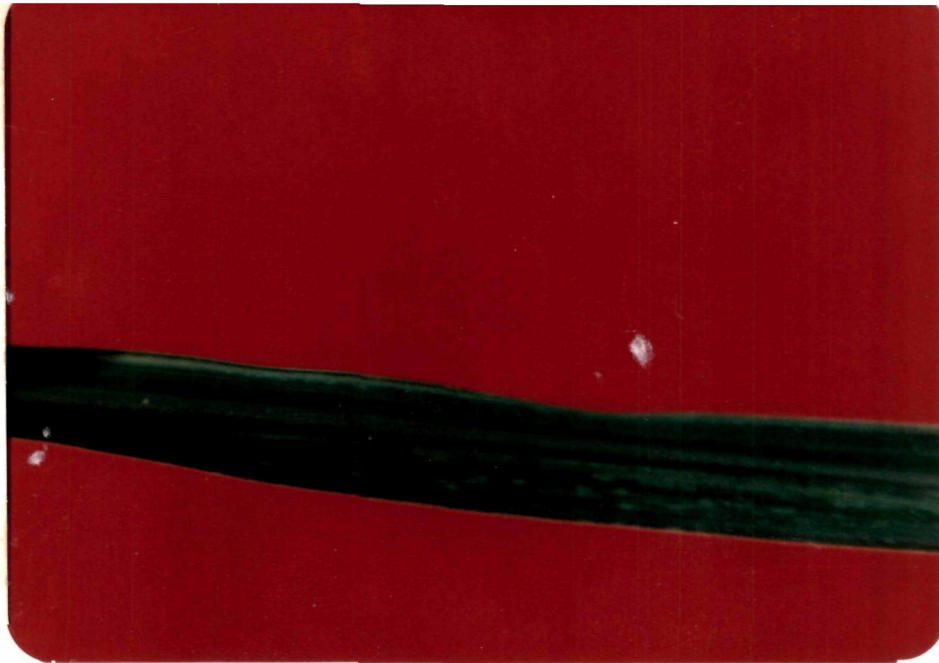


Fig. 32a



Fig. 32b

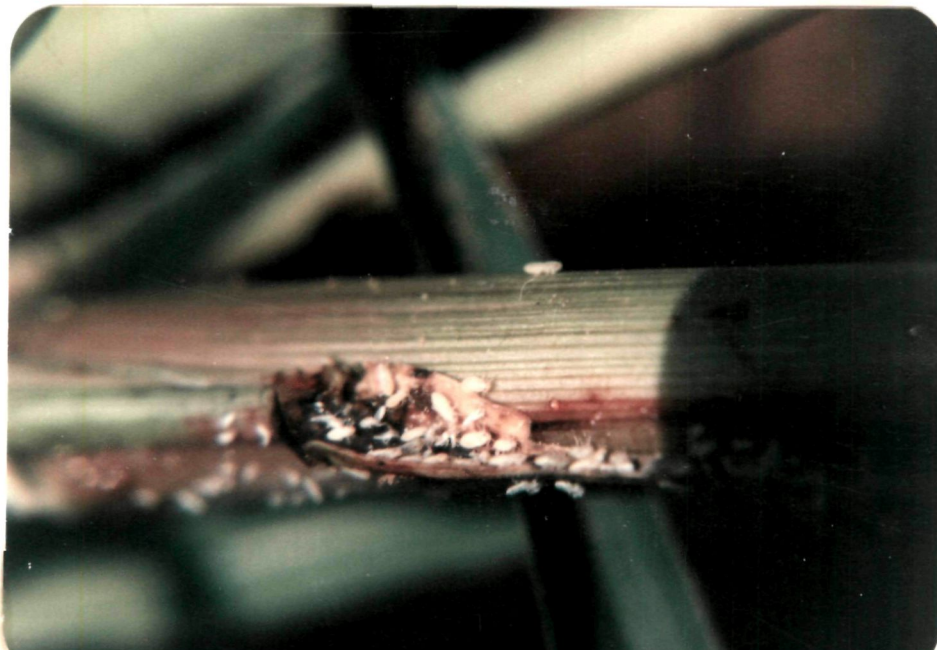


Fig. 33

Table 34: Effect of sorghum stripe virus infection on chlorophyll, NPK content and growth parameters of sorghum seedlings.

Growth parameters ^b		Healthy	Diseased	Reduction over control	Per cent loss
Height (cm)		52.50 ^c	19.66	32.84	62.55
Leaf number		6.80	5.30	1.50	22.05
Shoot:	Fresh	4.24	0.73	3.51	82.78
	Dry	0.48	0.13	0.35	72.91
Root:	Fresh	2.51	0.32	2.19	87.25
	Dry	0.37	0.03	0.34	91.89
Leaf area:	1	4.53	3.66	0.87	19.20
(sq. cm)	2	6.94	5.23	1.71	24.63
	3	12.31	8.30	4.01	32.57
	4	25.44	12.50	12.94	50.86
	5	47.81	16.40	31.41	65.69
	6	69.33	22.30	47.03	67.80
Chlorophyll		0.88	0.46	0.41	46.98
(g/fresh weight)					
Nitrogen	Shoot	22.00 ^d	40.00	-18.00	81.81
	Root	11.00	22.00	-11.00	100.00
Phosphorus	Shoot	6.00	7.00	-1.00	16.70
	Root	6.00	4.00	2.00	33.33
Potassium	Shoot	64.00	60.00	4.00	6.25
	Root	36.00	24.00	10.00	27.80

^a 2-leaf stage used for inoculation, 2 insects/seedling

^b Growth parameters recorded 4 weeks after inoculation

^c Values given are mean of three replicates with 5 plants in each replication

^d Values given in mg/gram of dry weight of plant materials

Fig. 34. Sorghum seedlings severely affected after inoculation with SStV using Perigrinus maidis



Fig. 34

tent of 40 mg and 22 mg/g of sample was noticed in infected shoot and root when compared 22 and 11 mg/g in healthy plants. Phosphorus content was found to be similar in both healthy and infected plants. Whereas potassium content was found slightly more in healthy than in infected plants.

4.7.2 Effect of SStV on plant growth

The effect of SStV infection on various growth stages (2, 4, 6, 8 and 10 leaf stages) was studied after inoculation in glasshouse experiment (Fig. 35). Seedlings inoculated at 2 and 4 leaf stage did not reach flowering stage but death of the infected seedlings was observed. Plant inoculated at 6, 8 and 10 leaf stages reached flowering.

The data were recorded on different growth parameters from plants inoculated at 6, 8 and 10th leaf stages and presented in Table 35. All the growth stages were susceptible for infection. Days required for symptom expression was 8.6, 14 and 17.7 days at 6, 8 and 10 leaf stages inoculation respectively. As the age of the plant increased at inoculation the effect on growth parameters decreased. It was found that there was no significant difference in number of internodes produced both in infected and healthy plants. The mean internodal length was reduced to 3.3, 5.96 and 7.80 cm respectively when inoculated at 6, 8 and 10 leaf stages when compared to 12.23 cm in healthy plants. Similarly the fresh and dry weight of shoot and roots increased as the plant age increased at inoculations. The data presented indi-

Table 35: Effect of SSTV infection at various growth stages of sorghum in glasshouse.

Growth stages	Days to express symptoms	No. of leaves/plant	Infected leaves/plant	Plant height (cm)	Number of nodes	Mean internode length	Shoot wt (gms)		Root wt (gms)	
							Fresh	Dry	Fresh	Dry
6-leaf	8.6 ^c	10	5.7	49.4	9.6	3.30	32.4	7.96	8.43	2.05
8-leaf	14.0	10.3	4.3	73.3	10.0	5.96	45.0	13.41	20.26	5.90
10-leaf	17.7	11.0	2.0	90.0	10.2	7.80	56.1	15.13	23.80	8.62
Healthy		11.7	-	127.0	11.6	12.23	62.3	18.60	29.70	10.76
Mean	10.11		5.9	85.2	10.1	7.4	49.1	13.80	20.62	6.88
SFM	0.79		0.14	2.86	0.12	0.19	1.68	0.51	0.69	0.20
CD (5%)	0.24		0.43	8.63	0.36	0.57	5.10	1.55	2.11	0.61

a Plants harvested after earhead emergence in all stages

b Five viruliferous adults/plant used for inoculation

c Values given are mean of five replicates

Table 36: Correlation matrix for sorghum plant growth parameters and SSTV infections.

Parameters	1*	2	3	4	5	6	7	8	9
1. Days to express symptoms	1.0000								
2. Infected leaves/plant	-0.9861	1.000							
3. Plant height (cm)	-0.4742	0.5905	1.000						
4. Number of internodes	-0.4094	0.5356	0.9961	1.000					
5. Mean internodal length	-0.5219	0.6338	0.9985	0.9907	1.000				
6. Fresh shoot weight	-0.2344	0.3622	0.9659	0.9778	0.9504	1.000			
7. Dry shoot weight	-0.3043	0.4435	0.9752	0.9910	0.9640	0.9813	1.000		
8. Fresh root weight	-0.2450	0.3885	0.9602	0.9811	0.9458	0.9811	0.9980	1.000	
9. Dry root weight	-0.2602	0.3911	0.9735	0.9859	0.9594	0.9986	0.9900	0.9890	1.000

* 1. Days to express symptoms	2. Infected leaves/plant
3. Plant height (cm)	4. Number of internodes
5. Mean internodal length	6. Fresh shoot weight
7. Dry shoot weight	8. Fresh root weight
9. Dry root weight	

Fig. 35. Effect of sorghum stripe virus on various
sorghum plant growth stages at infection

Age of seedling at inoculations:

- | | | | | | |
|---|------------------------|---|----------|---|------------|
| 1 | One week | 2 | Two week | 3 | Three week |
| 4 | Uninoculated (Healthy) | | | | |



Fig. 35

cates the fresh and dry weight of shoot and root was 32.4 and 7.96 and 8.43 and 2.05 g at 6 leaf stage, 45.0, 13.41 and 20.6, 5.90 at 8 leaf stage and 56.1, 15.13 and 23.80, 8.62 at 10th leaf stage respectively. The comparative fresh and dry weight of shoot and root was 62.3, 18.6 and 29.7 and 10.76 grams were observed in healthy plants. The correlation matrix among the growth parameters at various stages of infection are presented in Table 36.

4.7.3 Effect of SStV on grain yield of sorghum

The age of the plant at infection has greatly influenced the plant growth and grain yield of sorghum (Table 37). The mean number of 6 infected leaves with symptoms were produced when the plant got infected at the age of 20 days old, whereas one leaf showed symptom when the plant got infected at 45 days. The maximum reduction in plant height (46.2 cm) was observed when the plants got infected at an early stage. Plant height was 103.2 cm when the plants got infected at 11th leaf stage (45 days) compared to 135.2 cm in healthy plants.

The effect of SStV on reduction in grain yield ranged from 65 to 89 per cent at different stages of infection was observed. The results also showed that the mean grain weight of 3.2 grams/plant served when the crop got infected at 20 days old, whereas it was 16.8 grams/plant when the plant got infected at 10th leaf stage. The grain yield in terms per acre when extrapolated it will be 102.4 kg/acre from the plants infected at early stage against 684.8 kg/acre if infected at later growth stages of

Table 37: Effect of SStV on plant height and grain yield of sorghum (cv. SPV-351) at various growth stages under field conditions

Age of ^a plant at inocula- tion in days	No. of infected leaves/ plant at maturity	Plant ^c height (cm)	Grain yield/ plant (g)	Grain yield (Kg/acre)	Loss in yield (Kg/acre)	Per cent loss
20(5) ^b	6	46.2	3.2	102.4	1903.6	89.63
25(7)	5	52.0	6.5	208.0	1798.0	89.60
30(8)	4	76.0	9.7	310.4	1695.6	84.60
35(9)	3	79.0	14.1	451.2	1554.8	77.51
40(10)	2	98.5	16.8	537.6	1468.4	73.20
45(11)	1	103.2	21.4	684.8	1321.2	65.86
Healthy	-	135.2	62.7	2006.0	-	-
Mean		71.0	19.2	614.3	1623.6	80.05
SEM		2.84	0.29	9.40	-	-
CD (5%)		8.46	1.88	27.90	-	-

^a Date of planting 10/8/91

^b Total number of leaves per plant at the time of inoculation

^c Average of 30 plants

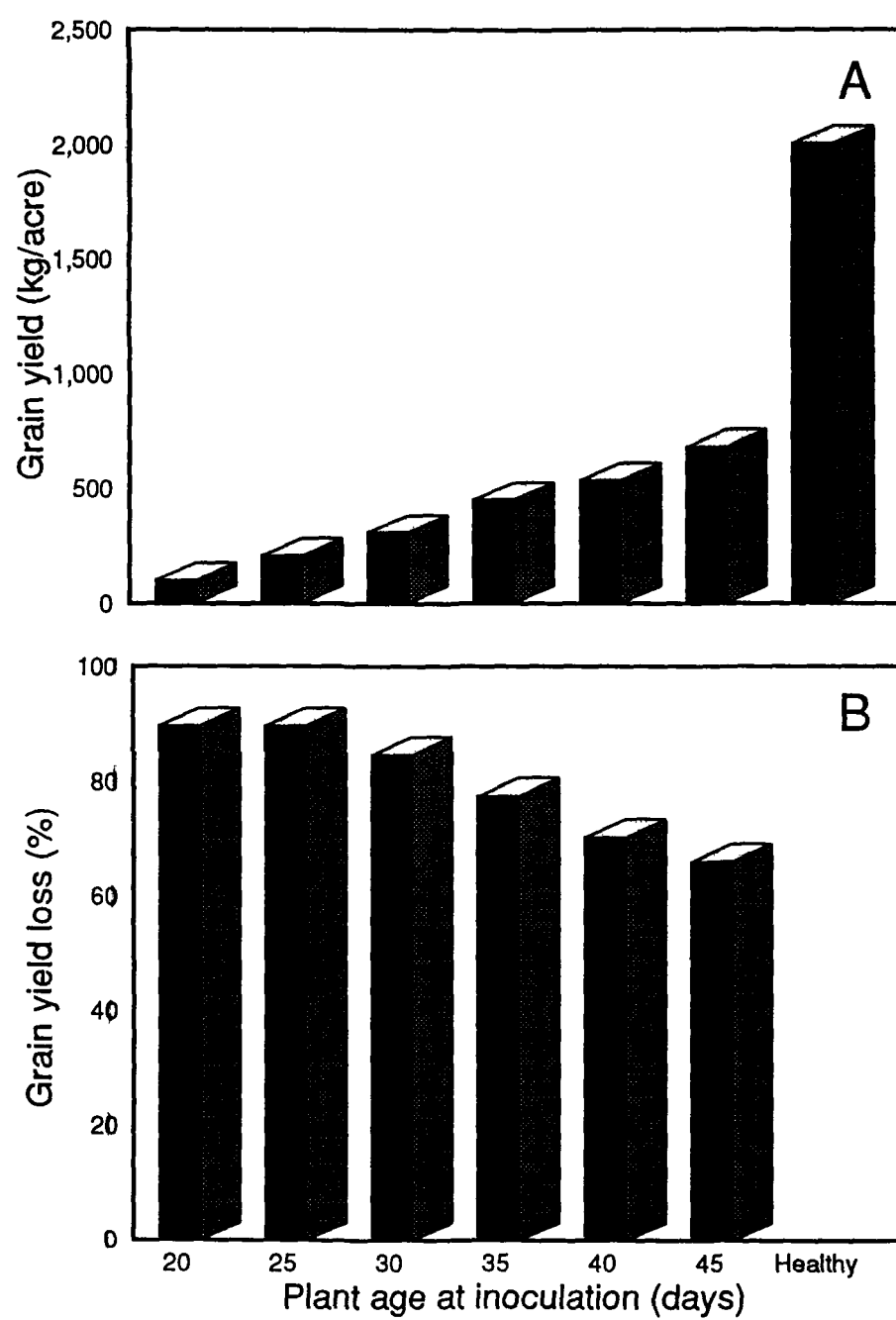


Figure 36. Effect of SStV on sorghum grain yield (kg/acre) (A) and percent yield loss (B) at different stages at inoculation

infection when compared to healthy plant with 2006 kg/acre. This suggests that the older the plant age at the time of infection the reduction in grain yield decreases (Fig. 36A). The per cent loss in grain yield also decreases with increase in age of plants at the time of infection (Fig. 36B). It was also found that there is a negative correlation between the crop stage at the time of infection to plant height ($r = -0.98$) and to grain yield ($r = -0.82$).

4.7.4 Detection of SStV in different parts of infected sorghum plant by Penicillinase based ELISA

The presence or absence of SStV on different parts of infected plant was studied using PNC-ELISA. The infected sorghum plant showing symptoms in top three leaves was uprooted from the field at grain initiation stage. The samples were collected from different parts of the plant (Fig. 38) starting with initiating seed to roots and were processed for ELISA and the reactions were scored visually. The data (Table 38) showed that the virus could be detected in seed, glumes, peduncle, 3 infected leaves showing visual symptoms and five leaf sheaths from top. The virus could also be detected in all the 10 internodes of the infected plants, basal tillers and roots.

4.7.5 SStV titre in infected leaves

The concentration of SStV was estimated in infected leaves collected from SStV infected sorghum plant from the field at flowering stage. It was observed from the data (Table 39) that

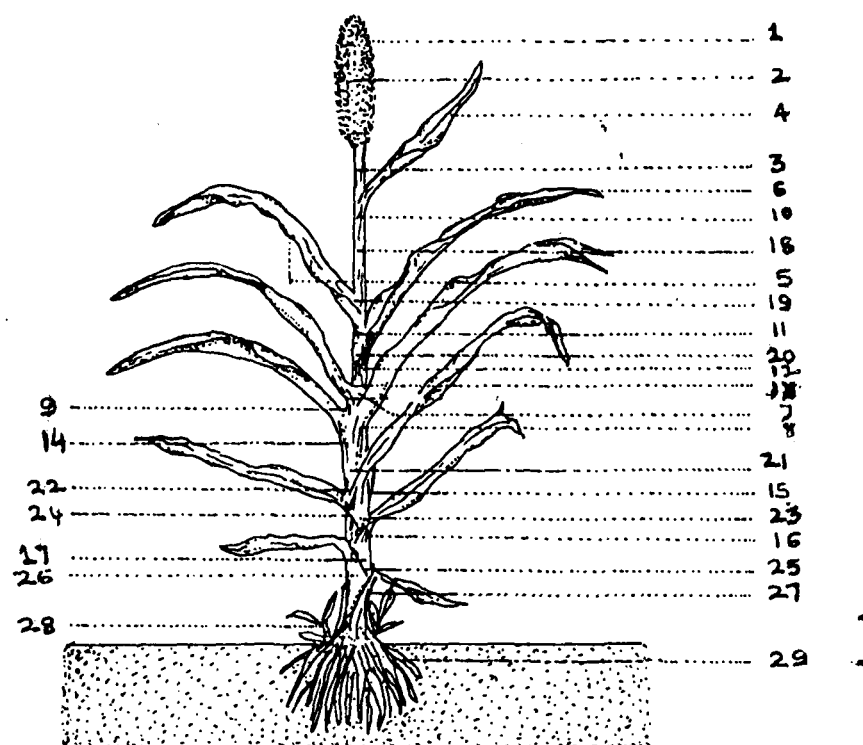


Figure 37. Samples collected from different parts of SStV infected Sorghum plant for detection of virus using ELISA.

Table 38: Detection of SStV in different parts of sorghum infected plant using ELISA

Sample number	Plant parts ^a	ELISA reaction ^b
1	Seeds at initiation	+
2	Glumes	+
3	Peduncle	+
4	Leaf - 1 (from top)	+
5	- 2	+
6	- 3	+
7	- 4	-
8	- 5	-
9	- 6	-
10	Leaf sheath - 1 (from top)	+
11	- 2	+
12	- 3	+
13	- 4	+
14	- 5	+
15	- 6	-
16	- 7	-
17	- 8	-
18	Stem - 1 (from top)	+
19	- 2	+
20	- 3	+
21	- 4	+
22	- 5	+
23	- 6	+
24	- 7	+
25	- 8	+
26	- 9	+
27	-10	+
28	Root	+
29	Basal tillers	+

^a Each sample tested in duplicate wells

^b ELISA reaction scored visually positive (+) and negative (-)

Table 39: Concentration of virus in different SStV infected leaves of sorghum plant

SStV infected Leaf Number ^a from base	Absorbance values ^b	
	1 hour	2 hours
6	0.216	0.820 ^c .
7	0.229	0.907
8	0.303	0.980
9	0.448	1.129
10	0.392	1.085
11	0.260	0.974
Healthy	0.000	0.000

^a Leaves are numbered from 6-11 from base towards tip and collected at flowering stage.

^b Values are absorbance at 630 nm

^c Mean absorbance values of triplicate wells obtained after deducting the mean absorbance values of buffer control.

the concentration of virus was minimum (absorbance value 0.820) on 6th leaf from the base where the first visible SStV symptom appeared. The highest absorbance value in 9th leaf (1.129) and decreased absorbance value was noticed in 10th and 11th leaves respectively, indicating the decline of virus titre in top two leaves.

4.8 Inoculation techniques

4.8.1 Threshold levels of P. maidis for SStV transmission

The results (Table 40) showed that twenty viruliferous insect for a batch of 10 seedlings (2 leaf stage) in polythene bag (Fig. 39) gave 100 per cent transmission, whereas with 1, 2, 4, 8, 12 and 16 viruliferous insects per set of 10 seedlings, the transmission was 6.0, 13.3, 26.0, 47.5, 53.6 and 71.4 per cent respectively. It was also observed (Fig. 39) that as the number of viruliferous insects increased for a set of 10 seedlings, the per cent transmission was also increased. The data also indicates that there is positive correlation ($r = 0.98$) between the number insects and per cent SStV transmission.

4.8.2 Inoculation of individual seedlings

Single seedling inoculation techniques was employed to know the efficiency of SStV transmission with 2 viruliferous insects per seedlings (Fig. 39). The results (Table 41) indicate that a batch of 20 seedlings inoculated individually, a mean of 53.3 per cent SStV transmission was observed from an average of three

Table 40: Threshold levels of *P. maidis*^a populations on transmission efficiency of SSTV

Number of ^{a, b} insects/ seedlings	Total seedlings	Seedlings infected	Per cent ^c infection
1	50	3.0	6.0
2	50	6.6	13.3
4	45	12.0	26.0
8	48	23.0	47.5
12	49	26.0	53.6
16	49	31.0	63.8
20	50	49.0	97.0

^a Acquisition access period 4 days, incubation period 10 days and inoculation access period 48 hrs

^b Group of 10 sorghum seedlings raised in polythene bags were inoculated by using 1-20 adult *P. maidis*.

^c 2-leaf stage was inoculated

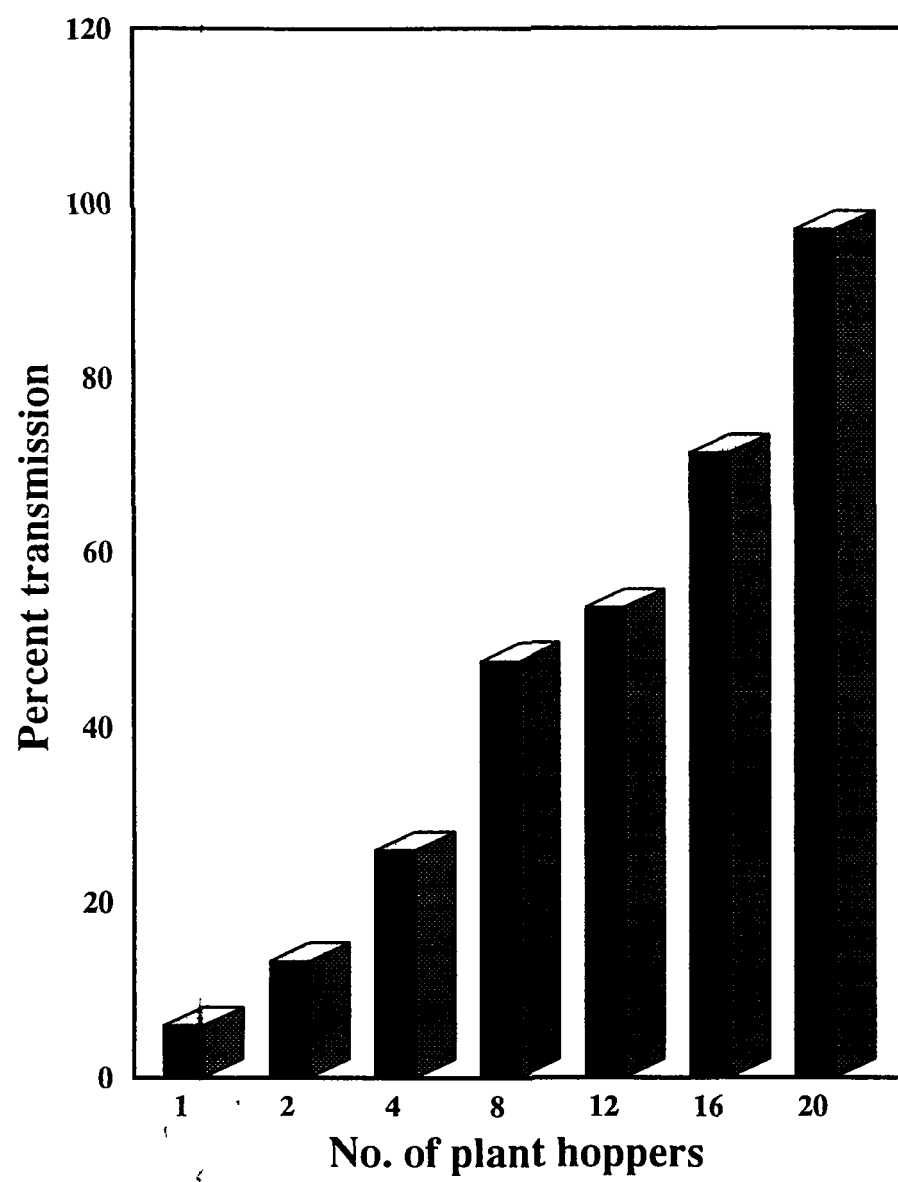


Figure 38. Effect of number of plant hoppers on percent transmission of sorghum stripe virus

experiments. The SStV symptoms appeared on leaves 8 days after inoculation (Fig. 40).

4.8.3 Inoculation of group of seedlings

A group of ten sorghum seedlings was inoculated (Fig. 42a) at two leaf stage to know the efficiency of SStV transmission. The data (Table 42) indicate that when the group of 10 seedlings was inoculated by using 10 viruliferous insects the mean SStV transmission of 29.7 per cent was observed. In another experiment, when group of 10 seedlings was inoculated by using 20 viruliferous insects the average transmission was found to be 98.6 per cent. The inoculated seedlings expressed SStV symptoms on young leaves 10-15 days after inoculation (Fig. 41&42).

4.8.4 Mass inoculation of sorghum seedlings

The results (Table 43) showed that 67.47 per cent of plants were infected when mass of sorghum seedlings were raised in rectangular container (Fig. 43).

4.8.5 Inoculation of grownup sorghum plants

The adult plant with 6 or 8 leaves inoculation technique in greenhouse conditions was demonstrated by using perforated polythene bag as inoculation chamber (Fig. 44). The data (Table 44) indicates the mean SStV transmission of 49.63 per cent was observed from three trials. This technique can be successfully used to inoculate the sorghum plants of 30 to 50 days old under field conditions (Fig. 45).

Table 41: Inoculation of individual sorghum seedling with SStV by Peregrinus maidis^a.

Experiment	Total ^{b,c} Seedlings	Seedlings infected	Per cent infection
I	20	10	50.00
II	20	10	50.00
III	20	12	60.00

^a Acquisition access period 4 days, incubation period 10 days, inoculation access period 48 hrs

^b 2 insects per seedlings used.

^c 2 leaves stage was inoculated.

Table 42: Inoculation of groups of sorghum seedlings with SStV by P. maidis^a.

Number of insects	Experiment Number	Total ^b seedlings	Seedlings infected	Per cent infection	Mean
10	1	10	2.8	28.00	
	2	10	3.0	30.00	
	3	10	3.1	31.00	29.70
20	1	10	10.0	100.00	
	2	10	9.6	96.00	
	3	10	10.0	100.00	98.60

^a Acquisition access period 4 days, incubation period 10 days, inoculation access period 48 hrs

^b 2-leaves stage was inoculated, PVC tubes was used for enclosing planthoppers on sorghum seedlings.

Fig. 39. Single sorghum seedlings inoculation using
viruliferous perigrinus maidis

Fig. 40. Sorghum leaves of young seedlings showing
SStV symptoms 8-10 days after inoculation



Fig. 39



Fig. 40

Fig. 41. Group of seedling inoculation of SStV using viruliferous P. maidis

Fig. 42. Group of seedling inoculated showing SStV symptoms on young leaves



Fig. 41



Fig. 42

Table 43: Mass inoculation of sorghum seedlings raised in rectangular container with SStV by P. maidis^a.

	Total ^b seedlings/ container	Plants infected	Per cent infection
Experiment 1	36	24	66.70
	33	26	78.80
	35	22	62.85
	39	27	69.20
	40	23	57.50
Experiment 2	40	28	70.00
	37	24	64.86
	34	24	70.60
	40	27	67.50
	39	26	66.70
Mean	37	25	67.47

^a Acquisition access period 4 days, incubation period 10 days, inoculation access period 48 hrs, vectors used in the ratio of 2 insects per seedlings

^b 2-3 leaf stage at inoculation, nylon mesh (size 40) was used for enclosing planthoppers on sorghum seedlings.

Fig. 43. Mass inoculation of young sorghum seedlings with SStV using
P. maidis

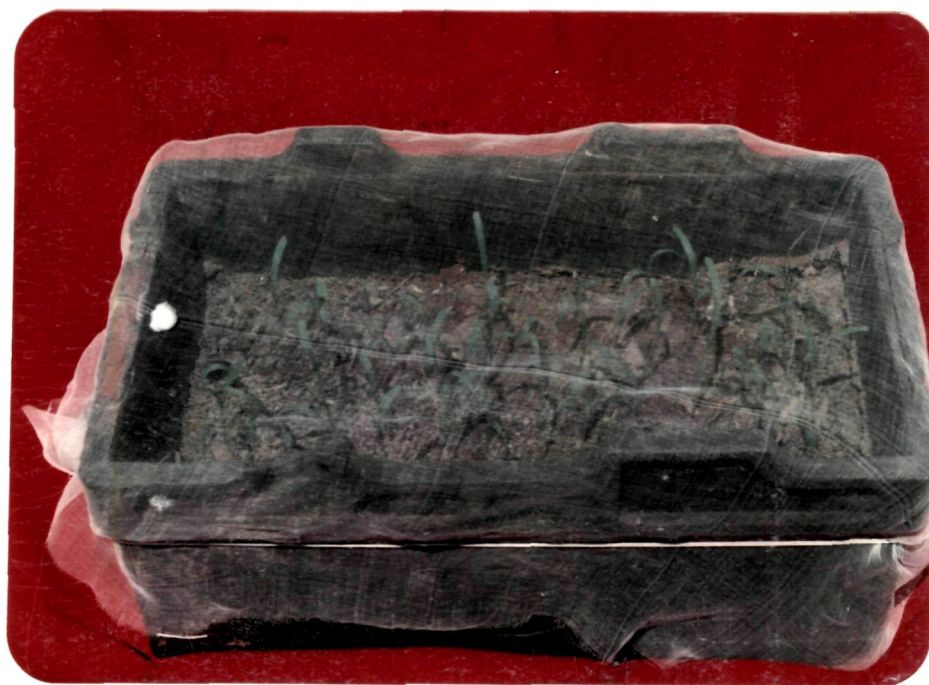


FIG. 13

Table 44: Effect of grown up sorghum plant inoculation to sorghum stripe virus infection by P. maidis.

Experiment number	Total ^{a,b,c} plants inoculated	Number of plants infected	Percentage of infection
1	45	21	46.70
2	45	23	51.10
3	45	23	51.10

^a P. maidis was given AAP 4 days, incubation period 10 days, IAP 48 hrs.

^b Group of 5 insects/plant

^c 7-8 leaf stage at inoculation

Fig. 44. Grown up sorghum plants inoculation with SStV
using polythene bag as inoculation chamber



Fig. 14

4.8.6 Comparison of screening techniques for efficient SStV transmission

A comparative study of five inoculation techniques (Fig. 45) was conducted in a replicated trial under glasshouse conditions to know the most effective and simple inoculation technique to use in large scale screening of sorghum cultivars for resistance sources. The results (Table 45) showed that the group of seedlings (2 leaf stage) inoculated with PVC plastic bottles as cages resulted 95 per cent infection. 45.8 per cent transmission was observed when adult plants were inoculated using perforated polythene bags as inoculation chamber. 65.8, 65.0 and 50.0 per cent infection was observed when metal framed cages, rectangular container and individual seedling inoculation technique were employed respectively.

It was observed that among the inoculation techniques tested set of seedlings at 2 leaf stage in polythene bag using PVC plastic bottles to enclose 2 viruliferous insects per seedlings was found to be simple and efficient inoculation technique. The flow chart of this inoculation technique was presented in Fig. 46.

4.9 Varietal screening

Group inoculation technique described in Fig. 47 was used for screening sorghum germplasm, breeding lines, varieties, hybrids and other materials to evaluate resistance sources available against sorghum stripe virus (SStV) disease. The susceptibility levels for SStV in each categories of sorghum

Table 45: Comparison of screening techniques for SStV infection by using *P. maidis*^a.

Screening ^b technique	Total seedlings	Number infected	Per cent ^c infection
1	20	11.0	50.0
2	20	19.0	95.0
3	40	26.0	65.0
4	30	19.7	65.8
5	30	13.7	45.8
Mean		17.9	64.35
SEM		0.85	2.69
CD (5%)		2.52	7.99
CV (%)		9.51	8.39

^a Acquisition access period 4 days, incubation period 10 days, inoculation access period 48 hrs, 2 insects/seedling.

^b 1 Individual seedlings
 2 Group of seedlings in polythene bags
 3 Mass inoculation of seedlings in rectangular container
 4 Metal framed cages
 5 Adult plants using perforated polythene bags with five insects per plant.

^c Mean of four replicates

Fig. 45. Inoculation techniques for screening sorghum stripe virus disease

- (1) Individual seedling
- (2) Group of seedlings
- (3) Seedlings in rectangular container
- (4) Metal frame cages
- (5) Adult plants

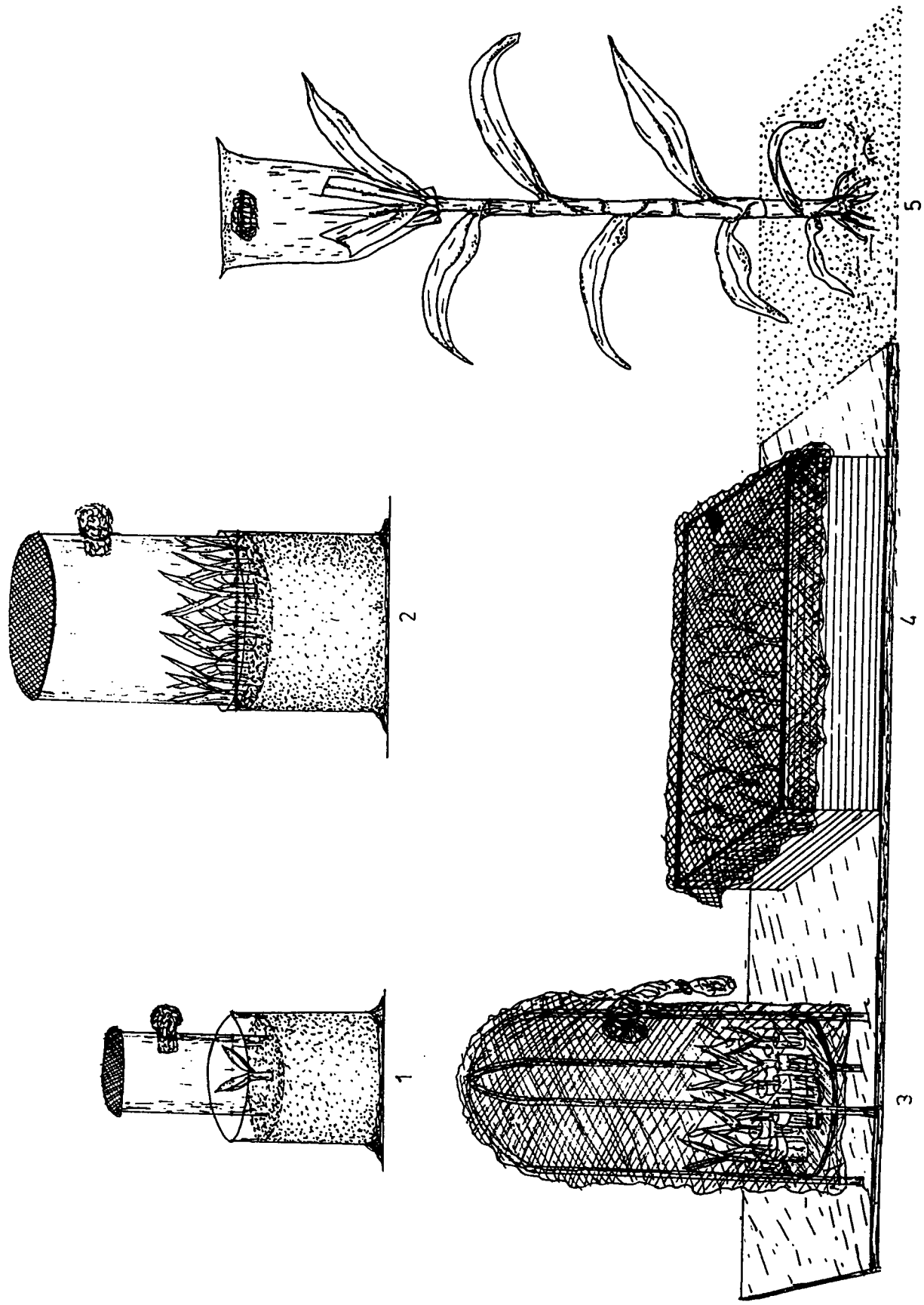


Fig. 45. Inoculation technique for screening sorghum stripe virus disease

SCREENING TECHNIQUE

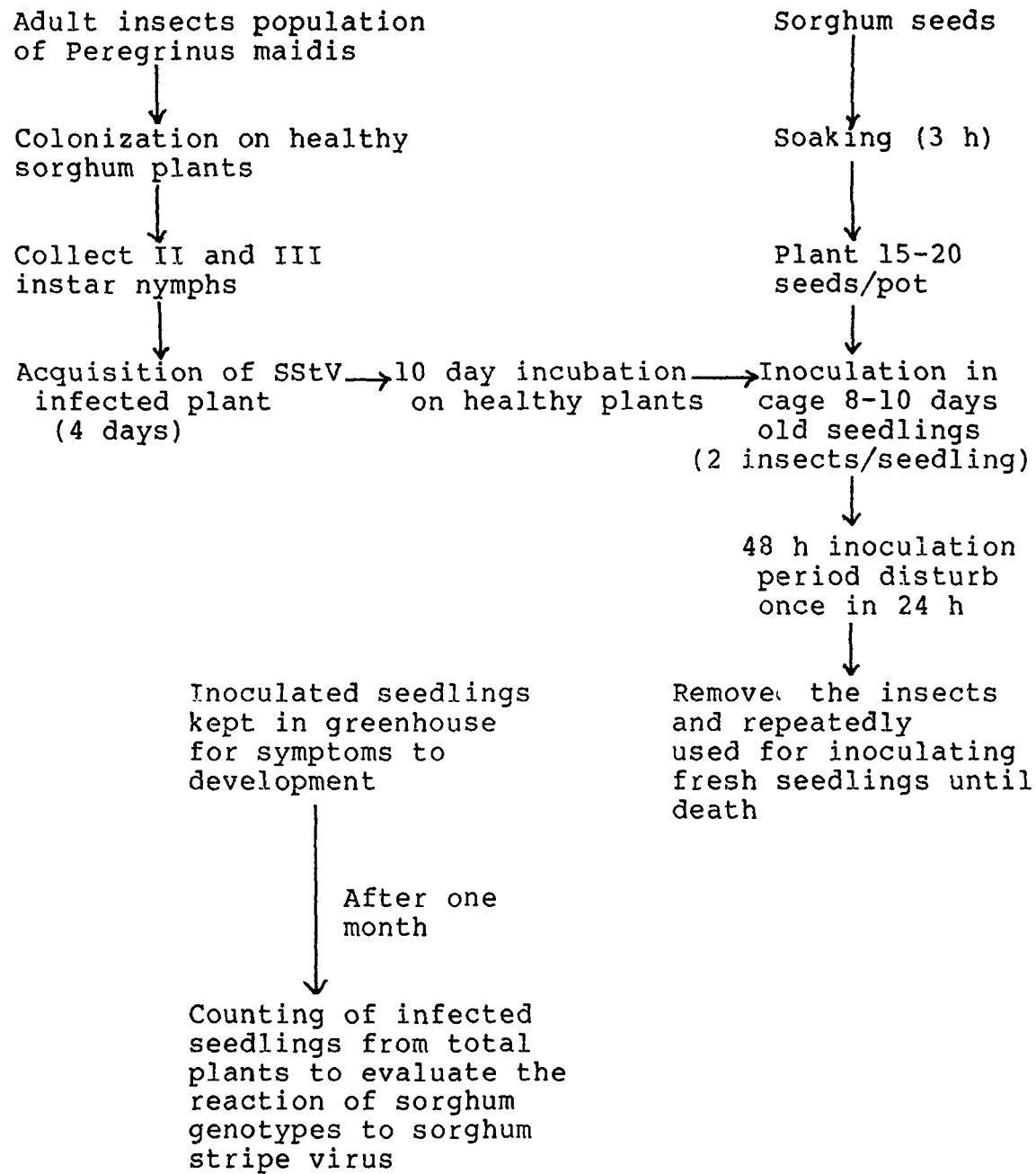


Fig. 46 Flow chart for screening of sorghum genotypes to sorghum stripe virus disease (SStV) using viruliferous planthopper (*Peregrinus maidis*) under glasshouse.

plant materials screened were recorded and presented as per cent SStV infection.

4.9.1 Reaction of sorghum germplasm to SStV

Five sorghum cultivars in each race of Bicolor, Durra, Kafir, caudatum and Guinea were inoculated at 2 leaf stage in polythene bags by group inoculation screening technique. The results showed (Table 46) that the susceptibility levels to SStV ranged from 18 to 92 per cent infection. Out of 28 germplasm lines tested the SStV susceptibility range of 10-20 per cent (3), 21-40% (6), 41-60% (7), 61-80% (8) and 81-100% (4) was observed. The susceptible sorghum check CSH 9 showed 86.6 per cent infection.

4.9.2 Reaction of sorghum breeding lines from ICRISAT lines to SStV

Forty sorghum breeding lines from ICRISAT were tested by group seedling inoculation technique. The screening data (Table 47) showed that the SStV susceptibility ranged from 11.7 to 60.0 per cent infection. The range of susceptibility among the breeding lines tested was 11-20% (3), 21-40% (26) and 41-60% (11) observed. Whereas the susceptible check CSH-9 showed 80 per cent SStV infection.

4.9.3 Reaction of sorghum hybrids and varieties

Sorghum material representing varieties and hybrids were screened for reaction to SStV. The data (Table 48) showed that

Fig. 47. Group seedlings inoculation technique in screening sorghum genotypes to SStV.



Fig. 47

Table 46: Reactions of different races of sorghum germplasm to SSTv

Sorghum ^{a, b} race	Genotype	Total ^c seedlings	Number infected	Per cent infection
Bicolor	IS 2	24	20	83.33
	IS 13	26	24	92.30
	IS 601	29	23	79.31
	IS 633	46	44	95.65
	IS 699	25	20	80.00
Durra	IS 917	24	22	91.66
	IS 1025	23	16	69.56
	IS 8542	22	15	68.18
	IS 11122	20	6	30.00
	IS 22697	21	16	76.19
Kafir	IS 9303	28	16	57.14
	IS 9306	25	19	76.00
	IS 9626	26	11	42.30
	IS 22238	22	7	32.00
	IS 22349	21	15	71.43
Caudatum	IS 7342	21	12	57.14
	IS 8248	24	10	41.66
	IS 9649	25	8	32.00
	IS 13441	20	6	30.00
	IS 18309	25	5	20.00
Guinea	IS 6758	28	18	64.28
	IS 7818	33	6	18.18
	IS 10195	28	10	35.71
	IS 17819	20	10	50.00
	IS 17895	20	4	20.00
	IS 14216	32	7	21.87
	IS 18867	34	17	50.00
	Sorghum virgratum CSH-9 (Susceptible check)	20	14	70.00
		30	26	86.66

^a P. maidis was given AAP 4 days, incubation period 10 days, IAP 48 hrs, 2 insects/seedlings was used for inoculation.

^b Germplasm Resource Unit (GRU), ICRISAT, AP, India

^c 2-leaf stage was inoculated

Table 47: Reaction of ICRISAT sorghum breeding populations to sorghum stripe virus^a.

Genotype	Total plants inoculated	Plants infected	Per cent infection
ICSB-1	16	7	43.75
ICSB-2	16	6	37.50
ICSB-3	16	6	37.50
ICSB-4	16	5	31.25
ICSB-5	16	5	31.25
ICSB-6	15	4	26.66
ICSB-7	16	8	50.00
ICSB-8	16	8	50.00
ICSB-9	16	6	37.50
ICSB-10	16	8	56.00
ICSB-11	15	8	53.33
ICSB-12	15	6	40.00
ICSB-13	15	3	20.00
ICSB-14	17	2	12.00
ICSB-15	16	3	18.75
ICSB-16	15	9	60.00
ICSB-17	14	5	35.71
ICSB-18	16	7	43.75
ICSB-19	17	8	47.05
ICSB-20	15	6	40.00
ICSB-21	15	4	26.66
ICSB-22	15	7	46.66
ICSB-23	15	4	26.66
ICSB-24	14	3	21.42
ICSB-25	16	8	50.00
ICSB-26	15	4	26.66
ICSB-27	15	5	33.33
ICSB-28	15	6	40.00
ICSB-29	16	4	25.00
ICSB-30	16	4	25.00

Table (contd...)

Genotype	Total plants inoculated	Plants infected	Per cent infection
ICSB-31	15	4	26.66
ICSB-32	16	4	25.00
ICSB-33	16	4	25.00
ICSB-34	15	6	40.00
ICSB-35	15	8	53.33
ICSB-36	17	5	29.41
ICSB-37	16	6	37.50
ICSB-38	15	5	33.33
ICSB-39	16	4	25.00
ICSB-40	16	5	31.25
CSH-9 (S. check)	15	12	80.00

^a P. maidis was given AAP 4 days, incubation period 10 days, IAP 48 hrs, 2 insects/seedlings was used for inoculation.

^b 2-leaf stage was inoculated

Table 48: Reactions of ICRISAT sorghum hybrids, varieties and A & B breeding populations to SstV^a.

Genotype	Total plants	Plants infected	Per cent infection
ICSH-89051	30	17	56.66
ICSH 90015	31	14	45.16
ICSH 90022	31	13	41.93
ICSH 90027	33	8	24.24
ICSH 90030	30	10	33.33
ICSH 90023	32	18	56.25
ICSH 90024	33	14	42.42
ICSH 110	30	11	36.66
ICSH 153	32	12	37.50
CSH-6	25	8	25.00
ICSA-11	31	16	51.61
ICSB-11	29	11	35.48
ICSA-22	33	20	60.60
ICSB-22	35	20	57.14
ICSA-30	39	20	51.28
ICSB-30	30	13	43.33
ICSA-31	28	15	53.57
ICSB-31	33	14	42.42
296 A	29	17	58.62
296 B	34	19	55.88
2219 A	15	5	33.33
2219 B	31	15	48.38
ICSR-33			
HR-750	33	10	30.30
ICSR 89015	20	4	20.00
ICSR 89016	36	11	30.55
ICSR 89018	33	11	33.33
ICSR 89037	14	4	28.57
ICSR 89064	32	7	21.87
ICSR 90006	18	8	44.44
CSV-4	15	3	20.00
CSH-9 (S.check)	20	17	85.00

Table (contd..)

Genotype	Total plants	Plants infected	Per cent infection
Varieties			
ICSV 88032	19	10	52.63
ICSV 88013	18	8	44.44
ICSV 88002	15	9	60.00
ICSV 89102	15	5	33.33
Hybrids			
ICSH 638	16	9	56.25
ICSH 228	13	8	61.53
ICSH 89020	18	11	61.11
ICSH 87891	17	15	88.23
ICSH 89018	15	8	53.33
ICSH 89051	16	11	68.75
ICSH 89123	15	5	33.33
ICSH 90005	13	5	38.46
Hybrids (Rabi)			
ICSH 86646	15	7	46.66
ICSH 87891	16	10	62.50
ICSH 86696	15	7	46.66
ICSH 871015	16	5	31.25
ICSH 871033	16	6	37.50
R lines			
ICSR-134	17	11	64.70
ICSR-153	15	9	60.00
ICSR-89022	15	6	40.00
ICSR-38	17	5	29.41
ICSR-174	16	7	43.75
ICSR-89018	16	6	37.50
ICSR-89019	17	7	63.63
ICSR-89028	15	3	20.00
CSH-9 (Check)	20	18	90.00

^a *P. maidis* was given AAP 4 days, incubation period 10 days, IAP 48 hrs, 2 insects/seedlings was used for inoculation.

^b 2-leaf stage was inoculated

out of 55 sorghum lines tested the SStV susceptibility varied from 20 to 60 per cent infection. However, the range of susceptibility was 31.25-88.23% (hybrids), 33.33-60% (varieties) and 20-64.7% (R lines), whereas the susceptible check showed 90 per cent SStV infection.

4.9.4 Testing downy mildew, anthracnose, leaf blight, charcoal rot, rust and grain mold resistant sorghum lines against SStV

The reactions of sorghum genotypes which were found to be resistant to downy mildew, anthracnose, leaf blight, charcoal rot, rust, grain mold were tested for SStV. Five genotypes resistant to each disease were inoculated by adult viruliferous *P. maidis* by group inoculation technique. The data (Table 49) indicates that none of the lines showed resistance to SStV. However, the susceptibility ranged from 8 to 66 per cent infection, whereas the susceptible check CSH-9 showed 93.0 per cent SStV infection.

4.9.5 Reactions of sorghum advanced varieties from AICRP (Sorghum) to SStV

Sorghum cultivars from advanced trials (AICRP Sorghum project) screened for SStV reaction by group seedlings inoculation technique in greenhouse. The results (Table 50) showed that out of 40 genotypes tested all the lines were found susceptible to SStV. However, the range of susceptibility was from 9.37 to 62.5 per cent. The susceptibility range was 1-10% (1), 11-20% (6), 21-40% (20), 41-60% (10) and 61-72% (2).

Table 49: Testing downy mildew, anthracnose, leaf blight, charcoal rot, rust and grain mold resistant sorghum lines against SStv^a.

Resistant sources	Genotype	Total ^b plants	Number of plants infected	Per cent infection of SStV
Downy mildew	QL-3	22	7	31.81
	IS 20450	26	17	65.38
	IS 20473	25	6	24.00
	IS 22227	23	8	34.78
	IS 20651	30	11	36.66
Anthracnose	A 2267-2	27	9	33.33
	IS 8283	49	15	30.61
	IS 9600	25	2	8.00
	ICSR 91006	53	6	12.52
	ICSV-173	27	14	66.66
Leaf blight	SP 9076-6	29	16	55.17
	SP 9079-10	30	15	50.00
	SP 9074-5	69	19	28.53
	SP 2946-2-1	23	8	66.66
	SP 9086-4-2	25	9	36.00
Charcoal rot	Q 101	21	14	66.66
	Q 102	22	11	50.00
	Q 103	24	14	58.33
	Q 104	79	6	8.00
	Q 36-1	25	6	24.00
Rust	SP 81703	18	4	22.20
	SP 84101-2	36	6	16.66
	SP 760512	22	4	18.80
	SP 76001	25	15	60.00
	PH 2908	31	10	32.25
Grain mold	IS 8545	27	11	40.74
	IS 8614	25	8	32.00
	IS 9471	21	9	42.85
	IS 17141	24	8	33.33
	IS 10942	66	29	43.93
	CSH-9 (Check)	30	28	93.33

^a P. maidis was given AAP 4 days, incubation period 10 days, IAP 48 hrs, 2 insects/seedlings was used for inoculation.

^b 2-leaf stage was inoculated

Table 50: Reactions of sorghum advanced lines from All India Coordinated Research Project (AICRP-Sorghum) to sorghum stripe virus^a.

Genotype	Total plants	Infected plants	Per cent infection
SPV 462	35	6	17.14
SPV 472	16	7	43.75
SPV 475	34	10	29.41
SPV 496	16	10	62.50
SPV 504	18	8	44.44
SPV 544	16	3	18.75
SPV 655	29	9	41.37
SPV 727	16	4	25.00
SPV 783	14	3	21.42
SPV 795	26	6	23.07
SPV 839	15	8	53.33
SPV 881	16	4	25.00
SPV 913	16	4	25.00
SPV 932	32	3	9.00
SPV 975	32	10	32.25
SPV 977	18	3	16.66
SPV 978	14	3	21.42
SPV 981	12	3	25.00
SPV 983	31	4	12.90
SPV 1006	15	3	20.00
SPV 1019	16	6	37.50
SPV 1046	36	9	25.00
SPV 1047	12	5	32.30
SPV 1048	12	3	25.00
SPV 1049	15	5	33.30
SPV 1055	15	6	40.00
SPV 1056	15	7	46.60
SPV 1061	12	6	50.00
CSV-5	16	3	18.75
CSV-9	34	14	41.17

Table (contd..)

Genotype	Total plants	Infected plants	Per cent infection
CSV-11	14	8	57.10
CSV-8R	16	5	31.25
CSH-13R	14	4	28.57
P 721	16	4	25.00
PJ 8K(Y)	18	10	55.50
PJ 8K(R)	15	6	40.00
TAM 2566	16	8	50.00
S.GIRLHR-1	12	3	25.00
H 35-1	16	10	62.50
IS 19349	15	3	20.00
CSH-9	20	17	85.00

a P. maidis was given AAP 4 days, incubation period 10 days, IAP 48 hrs, 2 insects/seedlings was used for inoculation.

b 2-leaf stage was inoculated

DISCUSSION

V DISCUSSION

The first virus disease described on sorghum [Sorghum bicolor (L.) Moench] was sugarcane mosaic virus (SCMV) identified by Brandes and Klapaack (1923). Later Tarr (1962) reviewed and reported 15 viruses as pathogens of sorghum. Since 1962, several other virus diseases on sorghum were added (Toler, 1979, May^hew_^ and Flock, 1981 and Toler, 1985).

Among the virus diseases on sorghum reported from India (Capoor et al, 1968; Mali and Bhagawat, 1975, Anahosur et al, 1980 and Garud, 1982) only maize mosaic virus (Naidu et al, 1989) and sorghum stripe virus disease (Peterschmitt et al 1991) have been purified and characterized as rhabdovirus and tenuivirus respectively. In nature both could be transmitted by a delphacid planthopper P. maidis (Ashmn.). Although sorghum stripe virus disease has been noticed in India, its systematic studies on economic importance, survey, diagnosis, virus-vector relations, epidemiology and its effect on plant growth and yield and other information are lacking.

The present investigations were undertaken on survey for SStV incidence, detection, virus-vector relationships, epidemiology, host-range, effect on growth and yield and to develop inoculation technique to screen varieties and hybrids for resistance sources.

Sorghum stripe virus disease on sorghum is characterized by

an appearance of chlorotic stripes and bands on infected leaves. The infected plant appeared stunted, premature death of infected seedlings at early stage and poor or no panicle formation. There are some similarities in the symptomatology of the various tenuivirus diseases (Everett and Lamey, 1969; Gingery et al, 1981; Greber, 1981; Slykhuis and Watson, 1958). Infected plants in general are stunted and yields are often drastically reduced depending on growth stages at the time of infection.

The survey conducted to assess the SStV incidence in sorghum growing areas revealed that the per cent incidence ranged from 0 to 13.5 during both kharif and rabi seasons. The disease was observed in most of the sorghum growing areas in Karnataka with mean incidence of 4.64 per cent. The highest per cent incidence of 13.5 per cent at one location was attributed to the presence of previous ratoon crop adjacent to the main crop. Similar observations were made by Capoor et al (1968); Chatterji and Nimbalkar (1977) and Peterschmitt et al (1991). The SStV was observed to be transmitted in nature by delphacid vector P. maidis (Ashmead, 1890) which is also a major pest on sorghum in South India (Chellaiah and Basheer, 1965; Agarwal et al, 1978; Singh and Rana, 1990). During the survey, it was also found that the prevalence of P. maidis populations ranged from 1 to 6 per plant in most of the sorghum fields.

The earliest detection of sorghum viruses is made with their observable symptoms and other effects on the host. Howev-

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er, such changes induced by plant viruses may be similar to those associated with other diseases, or nutritional deficiency or genetic characters of the host in the field and cause misidentification (Toler and Giorda, 1992). The ability to assay viruses is basic to all kinds of virological investigation. Diagnosis of specific virus disease on a routine basis is the requirement for the development of satisfactory control measures. Voller et al (1976a) for the first time used enzyme linked immunosorbent assay (ELISA) serological technique to detect plant viruses. Later Clark and Adams (1977) showed that microplate method of ELISA could be effectively applied for the detection and assay of plant viruses.

Serological diagnostic methods are preferred for virus detection and identification due to its sensitivity and convenience when large number of samples are to be tested. Several new techniques have been reviewed by Torrance and Jones (1981) and suggested ELISA method for large scale routine testing. The two enzymes that have been largely used in the ELISA for detection of plant viruses are alkaline phosphatase (ALP) and horse radish peroxidase (HRP) Clark and Bar-Joseph (1984). Penicillinase based ELISA described by Sudarshana and Reddy (1989) has been used for the detection of virus in both host and vector. The present ELISA results (Table 1) showed that the virus could be detected at higher dilution of antigen (1:6250) and antiserum (1:20,000).

ELISA based survey method described as multiple transfer

method (Gibbs and Gower, 1960) were used. The results showed that out of 276 samples collected 197 showed positive to ELISA test and this indicates the presence of SStV in most of the locations surveyed. The diagnostic procedure is needed to assure that even a single infected sample can be detected out of the total number of samples (Mauray et al, 1986).

The detection of virus in individual planthopper should facilitate epidemiological studies of plant viruses (Abdullah et al, 1978). ELISA has been successfully used by several workers to detect plant viruses in aphids (Gera et al., 1978; Chu and Francki, 1982) leafhopper (Azar and Banttari, 1981, Gingery et al, 1982) and in the planthopper Nilaparvata lugens vector of rice ragged stunt virus (Hibino and Kimura, 1982). In the present experiments the SStV could be detected in individual or in groups of 2, 5 and 10 planthoppers (P. maidis) after giving acquisition access on SStV infected source plants. SStV was also detected in field population of P. maidis from farmers field. Similarly Caciagli et al, (1985) and Cho et al, (1988) successfully used ELISA to detect tomato spotted wilt virus in thrips Frankliniella occidentalis and maize rough dwarf virus in Laodelphax striatellus. The result of present study clearly demonstrates the detection of SStV in field planthopper population by ELISA. However, the presence of virus in P. maidis did not assure that all the vector would transmit disease even though the SStV was detected in 30 per cent of field population as the infectivity assay showed only 6% infection. This indicate that ELISA do not

accurately predict the transmission efficiency of the vectors.

Kunkel (1922) first reported the transmission of maize mosaic virus by the vector P. maidis. The SStV an isolate of maize stripe virus on maize is transmitted in nature by planthopper P. maidis. Maize stripe virus was reported to be transmitted by P. maidis (Kulkarni, 1973; Tsai and Zitter, 1982) but not by Dalbulus maidis (Gingery et al, 1979) or by Sogatella kolophol (Greber, 1981). Maize stripe virus and rice stripe virus, rice hoja blanca belong to the new virus class tenuivirus (Gingery et al, 1981, Gingery, 1983; Morales and Nielsen, 1985 and Toriyama, 1983) which are not so far to transmitted by mechanical means. There is no report of transmission through seed or by dodder. Results on virus-vector relationship revealed that the rate of transmission of SStV was 45.34 per cent when single viruliferous insects were used for inoculation.

The minimum AAP, IAP and latent period was found to be 4 h, 1 h and 8 to 10 days respectively in P. maidis. The increased transmission was observed when the period of AAP, IAP and latent periods increased. P. maidis is able to acquire and transmit the virus in a minimum feeding period of 1 h and transmission period of 15 minutes. The virus has a latent period of 18 to 22 days in the vector which retains for its entire life (Capoor et al, 1968). The acquisition threshold for tenuivirus range from 10 minutes to several hours whereas inoculation threshold range from 30 sec. to nearly an hour. The latent period range from 3 to 36 days with mean of 7 to 21 days in the vector (Gingery,

1988). The proportion of infective individuals increased rapidly 14-21 days after acquisition in case of maize mosaic virus (Carter, 1941) and wheat chlorotic streak mosaic virus (Singnoret et al, 1977). The present studies showed that a latent period of 8 days was observed in young seedlings whereas it was 18 days in 10 leaf stage. All the growth stages of sorghum were found susceptible to SStV infection. Similar results were observed by Tsai, 1975; Trujillo et al, 1978, Mathew and Basu, 1986).

The SStV is transmitted by P. maidis in a persistent manner in the vector which serially transmitted the virus till death. In a serial transfer test, 8 out of 20 insects transmitted the virus until death. Two insects transmitted the virus continuously without any break whereas 6 insects transmitted the virus intermittently with frequent break. Similar results were also reported by Ammar et al (1989) where in the maize yellow stripe virus was transmitted by Cicadulina chinai in a persistent manner. Chlorosis striate mosaic was transmitted by Nesocluntha pallida upto 50 days without any occasional break (Greber, 1989), ragi streak virus by Cicadulina chinai was transmitted until death (Nagaraju and Viswanath, 1981). The intermittent and frequent transmission of maize stripe virus in a serial transfer test was also observed in P. maidis (Nault and Gordon, 1988). The prolonged latent period and transovarial transmission of plant viruses by their vector suggest that the virus multiplies in the vector. The infrequent transmission of SStV by P. maidis could be due to insufficient multiplication sites and lapse in

secretion of virus particles from salivary glands in to the salivary ducts in the ageing vector. The second factor may be that feeding by aged vector could be greatly reduced there by decreasing the chance for inoculating the virus.

The efficiency of virus transmission also depends on stages of vectors at the time of acquisition, sex and forms of the insects. The present results demonstrated 63.3% and 33.3% transmission was observed when the virus was acquired as young nymphs and adults respectively. Sinha (1963) showed that the transmission was found to be greater in nymphs than adults of Agallia constricta. Similarly the nymphs of P. maidis were more efficient transmitters than adults as vectors of maize stripe virus (Kulkarni, 1973; Autrey, 1980). The results (Nault et al, 1980) indicated that nymphs of Dalbulus maidis acquired and transmitted maize rayado fino virus efficiently (13.5%) than adults (3.5%) and transmission efficiency did not differ between males and females.

The results (Table 15) indicated that females of P. maidis transmitted efficiently (50%) than males (31.7%). In general, it was found that macropterous forms are more efficient transmitters (45%) than brachypterous (36.7%). Similarly the females are more efficient transmitters of rice stripe virus than males (Shinkai, 1962; Gingery, 1988) and the nymphs were better vectors than adults for maize stripe virus (Tsai and Zitter, 1982). The rate of transmission of maize chlorosis dwarf virus was found to be more by females (46%) than males (29%). The macropterous forms

of brown planthopper Nilaparvata lugens (Mathew and Basu, 1986) in general play a crucial role in epidemiology of rice grassy stunt.

The transovarial passage of virus through eggs to the progeny can be of importance in the epidemiology, assuming that the virus will be perpetuated within the vector even if virus susceptible plants are not available for long periods. The results confirmed the transmission of SStV through eggs laid by viruliferous female planthoppers. Out of 595 nymphs excised from eggs laid by viruliferous female planthopper only 3.0% of the nymphs transmitted SStV to healthy seedlings. Similarly Tsai and Zitter (1982) demonstrated that out of 78 nymphs excised from eggs only 8 individuals (6.3%) transmitted maize stripe virus. Several other workers also reported the transovarial passage of virus to their progenies, such as rice hoja blanca in Sogatodes oryzicola (Galvez, 1968), rice stripe virus in Laodelphax striatellus (Raga et al, 1988).

Seed transmission provides a very effective means of introducing virus to a crop at an early stage giving randomized foci of infection throughout the field. Barley stripe mosaic is the only definite seed borne virus to infect graminaceous plant. Its perpetuation incidence in barley and wheat is directly related to seed transmission supplemented by contact and pollen transmission (Slykhuis, 1967 and Timian, 1967). An attempt was made to find whether SStV could be seed transmitted in sorghum.

Results showed that the SStV could be detected by ELISA at different stages of seed development (pre-flowering to matured and dried seeds including glumes) harvested from infected plants (Table; 17). However, growing out test indicated that SStV was not transmitted through seeds harvested from infected seed to seedling even though SStV could be detected in dried seeds. Hamilton (1965) developed rapid and accurate serodiagnostic procedure for barley stripe mosaic virus in individual barley embryo and found it more reliable for large scale screening of commercial seed lot. Varma et al (1992) correlated the seed transmission of blackgram mottle virus with the amount of virus present in the embryonic axis and later in primary leaves. Attempts by several workers failed in transmission of maize mosaic and maize streak virus through seed (Autrey 1980; Pinner et al 1988). It is generally accepted, that true seed transmission to occur the virus must enter and survive in embryo or even if it enters later it gets eliminated. A low molecular weight RNA an inhibitor of virus infection was isolated from barley embryo, that specifically inhibited the initiation of viral synthesis and seed transmission in some species (Gunnery and Datta, 1987). Carrol (1972) detected seed transmissible strain of barley stripe mosaic virus in pollen, embryo and endosperm of barley seed but not in nontransmissible strain. The rate of 0.08 per cent seed transmission of maize dwarf mosaic virus was observed (Zhu et al, 1983). Various hypothesis have been advanced to account for the lack of seed transmission of viruses (Caldwell, 1962). Virus may disturb the normal relations of stamens and pistils, presence of inhibitory substance in embryo, breakdown of plasm-

desmata between endospermic and embryonic tissue, absence of vascular connection between the embryo and tissues of parent and virus has devastating effect on prophase of meiosis. One of these factors might be involved in SStV infected seed that makes the virus not expressed in seedlings even though the virus was present in the seeds.

The epidemiology of any disease largely depends on development and life cycle, dispersal behaviour of planthoppers, source of inoculum, its relation to crop genotype and environment. Tenuiviruses reported so far are known to infect only graminaceous plants and transmitted by planthoppers. Field survey during kharif and rabi seasons of 1991-92 revealed that sorghum stripe virus disease was prevalent in nearly all sorghum growing areas of Karnataka. The disease incidence varied from 0 to 13.5 per cent with mean incidence of nearly 5.0%. The SStV is transmitted in nature by a delphacid planthopper P. maidis which is also a serious pest on sorghum in Southern India. Agarwal et al, (1978) and Singh and Rana (1992). The results of the survey, it was observed the incidence of planthoppers in all sorghum fields surveyed showed a mean population of 2.7 per plant. The SStV and its vector are wide spread all over sorghum areas. The rate at which virus spread, both without and within the crops varies with source and mode of transmission. The newly infected plants soon become foci for secondary spread (Thresh, 1974 and Gibbs, 1983).

The role of cultivated crops and weeds on the occurrence and

spread of plant viruses is an integral part of the ecological aspects of virus transmission (Duffus, 1971). The epidemiology of virus disease in a given area may be a highly complex phenomena involving number of wild hosts, commercial crops and different insects. The natural wild plant populations are probably the most important sources of many economically important viruses.

In order to know the host range of SStV infection the graminaceous cultivated crops, fodder and weed grasses were artificially tested by inoculating with viruliferous P. maidis. The results from Table-30,32 and 33 showed that among the 11 cultivated crops and 35 fodder and weed grass only wheat (Triticum aestivum) and johnsongrass (Sorghum halepense) showed characteristic SStV symptoms. In ELISA test symptoms from both wheat and johnsongrass reacted positively and confirming the presence of virus in these hosts. Even though, the SStV is serologically related to maize stripe virus on maize (Kulkarni 1973, Gingery et al, 1981, Greber, 1981) but maize varieties were not infected by SStV with repeated inoculations using viruliferous P. maidis in our experiments. Similarly SStV could be transmitted to sorghum varieties but fail to infect many weed grasses tested (Peterschmitt et al, 1991). Additionally the P. maidis is not known to prefer maize even though it transmits maize mosaic virus (Naidu et al, 1989).

Wheat is one of the important cereal crops in the world. Several workers reported that wheat serves as an alternate host

for several cereal viruses which includes rice hoja blanca virus (Lamey et al, 1964), maize streak virus (Rose, 1974), barely yellow dwarf virus (Fargette et al, 1982), maize dwarf mosaic virus (Rose, 1978), maize yellow stripe virus (Ammar et al, 1989), maize stripe virus (Kulkarni, 1973). It was also true in the present tests that among the 11 cultivated crops tested only wheat crop grown in summer season could act as source of inoculum for early sorghum in kharif in northern part of Karnataka.

Among the fodder and weed grasses tested only johnsongrass (Sorghum halepense) proved to be the reservoir of both virus and vector during off season. Johnsongrass a perennial host commonly found in most of the field bunds, irrigation canals and in stagnant water ditches was found to harbour low population of planthopper with mild SStV symptoms was observed.

In our experiment, with artificial inoculation of fodder and grass seedlings in glasshouse using adult viruliferous planthoppers, only johnsongrass showed characteristic SStV symptoms to that of sorghum. It was also found that johnsongrass supported the colonization and further multiplication of planthopper from eggs to adults. The planthoppers did not prefer any other grass host tested for its multiplication. Several workers also reported that johnsongrass served as reservoir for cereal viruses and its vectors, maize mosaic virus (Tosic and Sutic, 1977), maize dwarf mosaic virus (Nault et al, 1980), maize stripe virus (Greber, 1981) and maize rayado fino

virus (Mangelsdorf, 1974). It is understood that most important sources of plant viruses are infected plants and extensive host range of both cultivated fodder and weed grasses. This host provides reservoir for viruses and vectors, a greater opportunity for widespread distribution, perpetuation and overwintering from one season to other season. Plant viruses with narrow host ranges may survive either because their host is perennial or vegetatively propagated or because of intimate host vector relationships. Perennial grasses cultivated as pasture immediately after main crop often support breeding of planthopper population. The size of planthopper populations determined by the number of host grass suitable for oviposition and development of nymphs.

Many cropping practices are known to facilitate the epidemics and spread of virus diseases. Some of the features are species cultivated, plant breeding practices, extended growing seasons by irrigation, monocropping and crop sequences one way or the other influence the spread of viruses and vectors. Major outbreaks of rice tungro disease were influenced by more intensive cultivations with short durations varieties, shorter intervals between planting and increased use of fertilizer and irrigation (Sogawa, 1976). The epidemic build up of virus governed largely by cropping practices and way in which they affect the viruses and their vectors have been reviewed (Thresh, 1982; Autrey and Recaud, 1983). Storey (1936) believed that the major source of maize streak virus was previously planted cereal crops. In warm regions, a succession of planting of irrigated maize is

commonly causing to increase the streak infection in later plantings (McClellan, 1947; Gorter, 1953).

The data from the field experiments under present studies (Table-23) showed the influence of continuous cropping over a period of an year on SStV incidence and build up of planthopper population. The SStV incidence in main crop, ratoon crop and overlap crop was 4.89%, 29% and 32% respectively. The planthopper population was also influenced by continuous cropping with an average of 1.57, 4.92 and 4.56 vector per plant in main, ratoon and overlap sorghum crop respectively. The results clearly indicated, that the successive cropping system plays an important role in SStV epidemics in later cropping. Typical overlapping sequence of crop during rainy season allows continuous breeding of Dalbulus maidis a vector of maize rayado fino virus, favouring the rapid virus spread (Rodrigo Gamez, 1983; Nault and Madden, 1985). Similarly Paliwal (1968) reported that MMV can overwinter in volunteer plants, developing from stubbles of cultivated sorghum and served as source of inoculum. The present results also confirmed that the stubbles and ratoon sproutings from previous sorghum crop served a source of virus inoculum and also vector population resulting in higher incidence of SStV in overlapping crop. Sorghum stripe virus also survived in dried leaf debris, left out glumes of threshed earhead which was detected by ELISA. SStV also survived in infected leaves stored at -10°C over a period of one year and for 5 months at $5-8^{\circ}\text{C}$ which was confirmed by ELISA. There are chances that accidental feeding by

planthopper in the left out debris in field might acquire virus and cause infection. Kondaiah et al (1976) and Kondaiah and John (1977) recovered rice tungro virus from infected dried leaves and feeding of Nephotettix virescens on leaf debris caused infection to rice plants.

The results from present studies (Table-37) showed that the SStV could be detected by ELISA in the entire stem and roots of infected plants. The presence of SStV in roots of perennial host (johnsongrass) was also confirmed by ELISA in present tests and in ratoon sproutings SStV symptoms were expressed. Khan et al (1991) reported that seedlings or rhizomes of several weeds which are vegetatively propagated served as source of rice tungro virus inoculum and later spread of potential vector, Nephotettix nigripictus in weed and fallow fields.

The serious epidemic outbreak of virus diseases at an early stage of crop growth when they are most susceptible consequently resulting in the loss in yield are often very high. It is indeed true in case of successive cropping sequences, the source of virus and viruliferous vectors were readily available. The incidence of twenty-nine per cent disease was observed in ratoon crop as compared to 5% incidence in main crop. It was also seen from the data (Table-23) the build up of planthopper population continued in the presence of irrigated ratoon crop during summer (Jan. to May) with a temperature ranging from 25 to 34°C with disease incidence of 29%.

Greber (1981) reported that sorghum rarely showed more than a trace of maize streak virus but the incidence was more common in sorghum X sudan grass hybrids grown as a rotational green manure crops in high rainfall districts. It is also possible that the persistent nature of virus in the vector for longer period might cause higher SStV incidence in fresh planting. The influence of cropping systems and continuous regenerations of weeds and volunteers in irrigated lands favoured the epidemics of rice tungro virus and maize streak virus (Bakker, 1970; Rose, 1972; Kiritani, 1979; Autrey, 1980, Autrey and Ricaud, 1983).

Sowing and harvesting dates have become more flexible in modern agriculture due to increased use of short duration varieties, irrigation and high fertilizer applications. These practices influence the survival of both virus and vectors by favouring the regeneration, dense stand of weeds, volunteers and stubbles left behind after harvest which act as a source of virus and vectors that readily spread the virus to subsequent crops.

Sorghum stripe virus disease on sorghum transmitted by delphacid planthopper is associated with severe chlorotic stripes and bands, stunted growth, premature death of seedlings and poor or no panicle formation. The early infection affect the initial establishment of sorghum seedlings and subsequent infection severely affects the plant growth and grain yield. Storey (1928) found that the age of the plants at the time of inoculation of maize streak virus had great influence on severity of infection ranging from 72% when infected at 8 days old and 35%

at 20 day old plants. The results (Table 34) from the present investigation revealed that SStV infection at seedling stage (1-2 leaf) severely affected the plant height, decreased leaf area, chlorophyll content, phosphorus and potassium contents, whereas nitrogen content was more in SStV infected plants than healthy plants. Preference for virus diseased plants by the vector has been reported (Maramorosch and Jenson, 1963) which is associated with increased content of soluble nitrogen in chlorotic plants. Similarly the reduction in plant growth parameters were also reported in sorghum due to red stripe virus infection (Pawar et al, 1990), maize streak virus in maize (Fesemisin et al, 1976).

The age at which plant gets infected with SStV has great influence on plant growth and grain yield in sorghum. The experimental results (Table 35) showed that the seedlings infected at 2 - 4 leaf stage resulted in death of seedlings before reaching flowering. Whereas plants infected at 6, 8 and 10 leaf stage did reach the flowering but with stunted plant growth and poor panicle formation. The decreased plant height, grain yield per plant and sterility was reported in maize due to maize mosaic virus infection (Autrey, 1980, 1983 and Tomic, 1983).

The results (Table 39) of field trials indicate the reduction in plant growth and grain yield at various growth stages of SStV infection. The reduction in plant growth 46.2 cm and 103.2 cm and grain yield of 3.2 and 21.4 grams in 20 and 45

days old plants due to SStV infection compared to plant growth of 135.2 cms and 62.7 grams in healthy plants. The loss in grain yield ranged from 65 to 89% at various growth stages of SStV infection. Maize plants infected with maize streak virus did not produce any yield at early infection, half the yield at 3 weeks and nearly full yield when infected at 8 weeks after planting (Van Rosenberg and Khun, 1977). The reduction in plant growth and grain yield in sorghum was also reported due to red stripe virus infection of sorghum (Vyavahare, et al 1989). Several research workers reported that the higher reduction in plant growth and grain yield was observed when plants at younger age, infected by rice hoja blanca (Jennings, 1963), maize dwarf mosaic virus (Alexander et al, 1984) and maize streak and mosaic virus infection in maize (Roca de-Doyle and Autrey, 1992).

The degree of grain yield loss is correlated with the severity of symptoms and stages at the time of infection. The stunting is due to reduction in leaf size and internodal length. The leaf number and number of internodes were little affected due to virus infection.

The success of breeding for disease resistance depended mostly on developing a simple, efficient and repeatable inoculation technique and mass rearing of insect vectors. Developing disease resistant varieties is the most feasible method for management of diseases because of the intricate epidemiology of the virus diseases. Monitoring the percentage of active virus transmitters in the reared populations helps to

indicate the number of planthoppers which should be released per test plant to obtain higher efficiency in virus infection. At the same time, it is necessary to know the stage of the crop for effective inoculations by the viruliferous vectors for higher and quick infection for evaluating the response of cultivars. It was observed from the results (Table 40) that the threshold levels of 2 viruliferous planthoppers per test plant at 2-3 leaf stage produce 95-100 per cent infection.

Lamey et al (1965) reported that the age of the plant has profound effect on its susceptibility to rice hoja blanca virus. Plants at 1-3 leaf stage were most susceptible and many of the field resistant cultivars found susceptible when inoculated at one leaf stage. Several inoculation techniques were evaluated in the present studies and compared (Table 45) to know the most effective inoculation method for screening sorghum cultivars. It was found that the technique of inoculation in sets at 2 to 3 leaf stage using 2 adult viruliferous P. maidis per test seedling resulted in as high as 95 to 100 per cent infection when compared to other methods described. Sakurai et al (1964) developed similar seedling test method which facilitated the testing for resistance to stripe virus disease on rice. This method was successfully used to screen several rice germplasm and breeding lines. Similar seedling inoculation technique was also standardized for screening grassy stunt of rice using the vector Nilaparvata lugens (Ling et al, 1970), maize streak virus using Cicadulina mbila as vector (Dabrowski, 1985), chlorosis of sorghum by

P. maidis (Capoor et al, 1968), maize streak virus by Cicadulina mbila and C. triangula (Zeilger et al, 1988).

Effective field screening of sorghum lines in addition to greenhouse is possible when test entries are planted adjacent to the previous crop where the vectors and virus source are readily available in abundance. Soto et al (1982) observed that leafhoppers Cicadulina mbila in adjacent field provided a source of maize streak virus through their natural migration into the adjacent test plots.

The most effective measure to control virus disease is by cultivation of genetically resistant plants, although adjusting planting dates for successive cropping to avoid high vector populations and source of virus inoculum can also help in reducing losses due to virus diseases. Germplasm, possessing high levels of stable heritable resistance must be identified and for which appropriate screening technique must be available (Rosenow, 1992).

Sorghum lines consisting of 193 germplasm, breeding lines, hybrids, varieties and lines resistant to other sorghum diseases were screened in greenhouse against sorghum stripe virus reaction. A group seedling inoculation technique described earlier was used to inoculate the seedling of 1-2 leaf stage at the rate of 2 adult viruliferous P. maidis per test plant. The results of the screening test revealed the none of the lines was resistant to SStV. Of the 392 varieties of sorghum vectored by

P. maidis, none of the lines was free from infection (Capoor et al, 1968).

Resistance to maize stripe virus was not detected in several maize and sorghum varieties (Greber, 1981) but Nault (1982) reported some tolerance to maize stripe virus in the teosinte relatives of maize (Zea diploperennis). All the maize varieties evaluated in the screen house over a period of several years were rated as highly sensitive to maize streak virus (Soto et al 1992). The evaluation of breeding lines indicated that resistance was simply inherited and attempts were made to incorporate resistance to high yielding maize cultivars.

In a greenhouse screening of rice stripe virus using viruliferous Laodelphax striatellus, it was found that all the 23 Japanese paddy cultivars were susceptible and 46 of the 53 upland rice cultivars were resistant (Sakurai and Ezuka, 1964). Yamaguchi et al (1965) reported that the resistance to rice stripe virus was due to combination of 3 factors, preference of the vectors, resistance to disease development and sensitivity to infection at different ages.

Conclusions

In India virus diseases on sorghum are caused by sorghum stripe virus, maize mosaic virus and red stripe virus. Currently research on sorghum viruses is not being carried out in any research centers. Sorghum stripe virus is one of the important diseases adversely affecting the plant growth and grain yield.

Preliminary surveys from the studies indicated that the incidence of SStV ranged from 0 to 13.5% and widespread prevalence of the disease was confirmed by ELISA test. In nature virus spreads in a persistent manner by a delphacid planthopper P. maidis. Johnsongrass, a wild relative of sorghum species and a perennial fodder grass, served as a reservoir of both virus and vector, playing an important role in perpetuation of the virus and vector throughout the year. It was also revealed that the grain yield loss due to SStV varied from 65 to 89% depending on the severity and stages of the crop at the time of infection. It was also found that none of the sorghum hybrids and varieties tested were resistant to sorghum stripe virus.

Present findings give preliminary information on incidence, transmission characteristics, survival of virus and its vector in nature and the economic importance of the disease. The most useful contribution in the present studies is the application of ELISA for the detection of virus in the host and the vector which is of much use for epidemiological studies. Epidemiology involves several factors, and the influence of each factor individually or in combination on SStV and its vector population needs indepth studies. Further work should be focussed on screening the diversified material from sorghum germplasm collection for sources of resistance. Future studies, one also needed to understand host-virus-vector relationships, to know the morphological or genetic basis to understand the resistance mechanisms for further manipulation of the disease either at crop or at vector level.

SUMMARY

VI SUMMARY

1. Penicillinase based direct antigen coating enzyme linked immunosorbent assay (PNC-DAC-ELISA) was standardized and successfully used to detect SStV in host and planthopper using antiserum raised against SStV.
2. The survey to assess the incidence of sorghum stripe virus (SStV) in sorghum growing areas of Karnataka during kharif and rabi 1991-92 revealed that the incidence varied from 0 to 13.5 per cent. The mean incidence of 4.48 per cent was observed both in kharif and rabi from 37 locations in 11 districts. In nature SStV is transmitted by the delphacid planthopper Peregrinus maidis.
3. During the field survey the populations of Peregrinus maidis a delphacid vector of SStV ranged from 1 to 6 with a mean population of 2.7 per plant.
4. ELISA was used during survey of SStV disease in 11 districts of Karnataka. Of 276 sorghum leaf samples collected from 37 locations, 197 samples reacted in ELISA.
5. Virus-vector relationships: The rate of SStV transmission was 45.34 per cent when single viruliferous P. maidis was used per seedling. Minimum of five viruliferous P. maidis required for 100 per cent infection of sorghum seedlings.

Minimum acquisition access period (AAP) and inoculation access period (IAP) were found to be 4 h and 1 h respectively. The latent period of SStV in P. maidis was found to be 8 days, whereas in host plants it was ranged from 8 to 18 days.

6. SStV could persist in the vector P. maidis throughout its life. SStV could be transmitted transovarially through eggs of P. maidis. Only 3 per cent of eggs carried the virus to next generation.
7. The transmission of 63.3 per cent was obtained when first instar nymphs were used for acquisition whereas with 2 to 4th instar nymphs and adults used for acquisition, the transmission was found to be 50% and 33.3% respectively. The macropterous forms transmitted (50%) more efficiently than brachypterous (30%). The females of P. maidis was found to be more efficient in transmitting SStV (53.3%) when compared to males (36.7%).
8. Sixty two per cent of the plants were infected with SStV when inoculated at coleoptile stage, whereas it was 46.4 per cent when plants were inoculated at 10th leaf stage. The results also indicated that the incubation period of virus in the host plants was 8 days at plumule stage and it was 18 days when plants were inoculated at 10th leaf stage.

9. Out of 975 seedlings raised from seeds collected from ten SStV infected plants, none of the seedlings expressed SStV symptoms one month after emergence. The results from ELISA revealed that SStV could be detected at different stages of seed development including dry seeds and glumes.
10. Epidemiological studies revealed that the field incidence of SStV was 4.9 per cent. The SStV incidence increased with increase in age of the plant, where as planthopper population reached peak (2.4/plant) up to 60 days and declined after flowering. SStV symptoms were observed on main plants, internode and basal tillers.
11. Incidence of 29.02 per cent was observed in ratoon sorghum crop. The planthopper population reached maximum at 60 days after planting and declined in later stages. In ratoon sorghum (20 days after sprouting) 57.5 per cent of the suspected plants in main crop expressed characteristic SStV symptoms.
12. SStV incidence of 32% was observed when sorghum was planted adjacent to ratoon crop. Planthopper population also increased in overlapping crop.
13. The spread of SStV and pattern of distribution during the cropping season indicated the clumped pattern of distribution under field conditions.

14. The efficiency of SStV transmission of planthopper collected from farmers field was found to be 6.0% on individual seedling inoculation and 9.25% infection was observed when group of seedlings were used for inoculations. Field collected P. maidis on infected plants showed 54% transmission when individual seedlings were used and 64.75% in group seedling inoculations.
15. SStV and plant hoppers survived in the field during off season on perennial host, johnsongrass. In nature planthopper colonization was also observed on johnsongrass. SStV could be detected upon storage at -10°C for more than a year in infected leaves, whereas at $5-8^{\circ}\text{C}$ it survived only for 5 months.
16. Out of 55 cultivars from 11 cultivated graminaceous host plant species tested by artificial inoculation with P. maidis, only wheat (Triticum aestivum) cultivars, Bijga yellow and Raj 1555 showed characteristic SStV symptom.
17. Among 20 fodder grasses and 15 weed grasses tested artificially using viruliferous P. maidis, only johnsongrass (Sorghum halepense) a perennial grass showed SStV symptoms and reacted to SStV antiserum in ELISA test.
18. SStV infection found to reduce the plant height by 62.55%, leaf area by 58.89%, fresh and dry weight of shoot by 82.78%

and 72.9%, fresh and dry root weight by 87.25 and 91.89%, loss of chlorophyll by 46.98% and increase in nitrogen content in diseased plants.

19. There was no flowering when sorghum seedlings were infected at coleoptile, 2 and 4 leaf stages, whereas at 6, 8 and 10 leaf stages at inoculation reached flowering with stunted plant growth and partial seed formations was observed.
20. The SStV could be detected by ELISA in all infected plant parts tested at seed formation stage including seed, glumes, peduncle, stems, basal tillers and roots. The presence of SStV in roots indicates the survival of SStV in the field stubbles and the infected sprouts served as host for virus and planthoppers. The concentration of virus was found to be high on 8th and 10th leaf in field infected plants which coincides with peak planthopper populations.
21. The results of field experiments revealed, that the plant growth was severely reduced ranging from 46.2 to 103.2 cm compared to 135 cm height in healthy plants depending on stages of infection. Similarly the grain yield reduction ranged from 1321 to 1903 kg/acre at various stages of infection in comparison to 2006 kg/acre in healthy sorghum plots.
22. The threshold level of 20 adult viruliferous P. maidis were found to cause 100 per cent infection when group of 10

seedlings were used for inoculation, whereas at 1, 2, 4, 8, 12 and 16 insects per 10 seedlings showed 6, 13.3, 26, 47.5, 53.6 and 71.4 per cent infection respectively.

23. Among the five glasshouse inoculation techniques evaluated, group seedlings inoculation technique using 2 viruliferous insects per seedlings resulted in 95 per cent infection, whereas individual seedlings, seedlings in rectangular container, metal framed cages and adult plant inoculation techniques resulted 50, 65, 65.8 and 45.8 per cent infection respectively. A flow chart procedure for mass screening of sorghum genotypes for SStV resistance was developed.
24. Out of 29 sorghum germplasm lines belonging to different sorghum races, 40 breeding lines, 55 hybrids and varieties, 30 sorghum lines resistant to other diseases and 40 advanced varietal sorghum lines screened using the standardized group seedlings inoculation techniques, none of the lines were resistant to SStV infection.

REFERENCES

VII REFERENCES

- Abdullah, G., Loebenstein, G. and Raccach, B., 1978, Detection of Cucumber mosaic virus in viruliferous aphids by ELISA. Virology, **86**: 542-545.
- Agarwal, R.K., Verma, R.S. and Bhnraj, G.S., 1978, Screening of sorghum lines for resistance against shoot bug Peregrinus maidis (Ashmead) (Homoptera : Delphacidae). JNKVV Res. J., **12** (1-4): 111.
- Alexander, J.D., Toler, R.W. and Miller, F.R., 1984, The effect of maize dwarf mosaic virus - B on the growth and yield of susceptible sorghum. Phytopathology, **74**: 625 (Abst.).
- * Amano, E., 1937, Relation of rice stripe virus with several gramineous plants. J. Pl. Prot. Japan, **24**: 774-780.
- Ammar, E.D., 1975, Effect of European wheat striate mosaic acquired by feeding on diseased plants on the biology of its planthopper Javesella pellucida. Ann. Appl. Biol., **79**: 195-202.
- Ammar, E.D., Gingery, R.E., Nault, L.R., 1987, Interactions between maize mosaic and maize stripe viruses in their vector, Peregrinus maidis and in maize. Phytopathology, **77**: 1051-1056.
- Ammar, E.D., Elnagar, S., Abdul-Ata, A.E. and Sewify, G.H., 1989, Vector and host-plant relationships of the leafhopper-borne maize yellow stripe virus. J. Phytopathology, **126**: 246-252.
- Anahosur, K.H., Kulkarni, K.A. and Parameswarappa, R., 1980, Red stripe disease of sorghum in Karnataka. Sorghum Newsl., **23**: 112.
- * Anonymous, 1975, Rep. Maurit. Sug. Indu. Res. Inst., **22**: 63-64.
- Anonymous, 1989, The State of Food and Agriculture. FAO, United Nations.
- Anonymous, 1990, Performance of jowar crop in Karnataka, Special Study Report No. 21. Monitoring and Evaluation Unit. Directorate of Agriculture, Bangalore, India.
- Anonymous, 1991, Agriculture: A reference manual 1991. Research and Reference Division. Ministry of Information and Broadcasting, Government of India.
- Ashmead, W.H., 1890, The corn delphacid. Delphax maidis. Psyche, **5**: 321-324.

- *Autrey, L.J.C., 1980, Studies on maize mosaic virus its strain and economic importance. Ph.D. Thesis, Univ. Exeter, England, 408 pp.
- Autrey, L.J.C. and Ricaud, C., 1983, The comparative epidemiology of two diseases of maize caused by leafhopper borne viruses in Mauritius. Pages 277-285 in : Plant Virus Epidemiology R.T. Plumb and J.M. Thresh Eds. Blackwell Scientific Publications, Oxford, 377 pp.
- Azar, M. and Banttari, E.E., 1981, ELISA virus transmission assay for detection of oat blue dwarf virus in Aster leafhoppers. Phytopathology, **71** (8): 858 (Abst.).
- Bakker, W., 1970, Rice yellow mottle a mechanically transmissible virus disease of rice in Kenya. Netherland J. Pl. Pathol., **76**: 53-63.
- Batte, R.D., Toler, R.W. and Bockholt, J., 1970, Effect of time of inoculation with dwarf mosaic virus strain-A on the agronomic characteristics of grain sorghum hybrids. Phytopathology, **60**: 581 (Abst.).
- Black, L.M., 1953, Occasional transmission of some plant viruses through the eggs of their vectors. Phytopathology, **43** : 9-10.
- *Berger, P.H., 1980, The relation of infectivity of maize dwarf mosaic virus in aphids. M.S Thesis, University of Minnesota, St. Paul, 99 pp.
- Bock, K.R., 1974, Maize streak virus C.M.I/A.A.B. Descriptions of plant viruses. No. 133, 4 pp.
- Brakke, M.K., 1988, Perspectives on progress in Plant Virology. Ann. Rev. Phytopathol., **26**: 331-350.
- Brandes, E.W. and Klapaak, P.J., 1923, Cultivated and Wild hosts of sugarcane or grass mosaic. J. Agric. Res., **24**: 257-262.
- Bradfute, O.E. and Tsai, J.H., 1990, Rapid identification of maize stripe virus. Phytopathology, **80**: 715-719.
- Brewbaker, J.L. and Flaviano Aquilizan, 1965, Genetics of resistance in maize to a maize stripe virus transmitted by Peregrinus maidis. Crop Sci., **5**: 412-415.
- Bradbent, L., 1957, Investigations of virus diseases of Brassica crops. London University Press, 94 pp.
- Caciagli, P., Casetta, A., 1986, Maize rough dwarf virus (Reoviridae) in its planthopper vector Laodelphax striatellus in relation to vector infectivity. Ann. Appl. Biol., **109**: 337-344.

- Caldwell, J., 1962, Seed transmission of viruses. Nature, **193**: 457-459.
- Canerday, J.W. and Guruskas, R.T., 1970, Effect of maize dwarf mosaic virus infection on yield, protein content and digestability of johnsongrass and sudan grass hybrid. Pl. Dis. Rep., **54**: 424-426.
- Capoor, S.P., Rao, D.G. and Varma, P.M., 1968, Chlorosis of sorghum. Indian J. Agric. Sci., **38**: 198-207.
- Carroll, T.W., 1972, Seed transmissibility of two strains of barley stripe virus. Virology, **48**: 323-326.
- Carter, W., 1941, Perigrinus maidis (Ashm) and the transmission of corn mosaic I. Incubation period and longevity of the virus the insect. Ann. Entomol. Soc. Amer., **34**: 551-556.
- Casper, R., 1977, Detection of potato leaf roll virus in potato and in Physalis floridana by ELISA. Phytopathol. Z., **90**: 364-368.
- *Castillo, J. and Hebert, T.T., 1974, Nueva enfermedad virosa afectando al maiz en el peni. Fitopatologica, **9**: 79-84.
- Catherall, P.L. and Griffiths, E., 1966, Influence of cocksfoot streak virus on the growth of single cocksfoot plants. Ann. Appl. Biol., **57**: 141-148.
- Chatterjee, S.W., 1971, Occurrence of stripe disease of maize in Maharashtra. Pages 725. In : Proc. 58th Indian Sci. Cong. III. 890 pp.
- Chatterjee, S.N. and Nimbalkar, M.R., 1977, Occurrence of maize stripe disease in Maharashtra. Indian J. Agric. Sci., **47**: 427-429.
- Chellaiah, S. and Basheer, M., 1966, Biological studies of Peregrinus maidis (Ashmead) (Araeopidae : Homoptera) on sorghum. Indian J. Entomol., **27**: 466-471.
- Cherian, C.M. and Kylasam, M.S., 1937, Preliminary studies on the freckled yellow and stripe disease on sorghum. Proc. Assoc. Econ. Biologists Coimbotore (1936) 57-63. Rev. Appl. Mycol., **17**: 169 (1938).
- Chiykowski, L.N., 1981, Epidemiology of diseases caused by leafhopper borne pathogens. Pages 106-159. In : Plant Diseases and Vectors. Ecology and Epidemiology. K. Marmorosch, K.F. Harris, New York, Academic Press.
- Cho, J.J., Mau, R.F.L., Hamasaki, R.T. and Gonsalves, D., 1988, Detection of tomato spotted wilt virus in individual thrips by ELISA. Phytopathology, **78**: 1348-1352.

- Choi, C.W., Gallenberg, D.J. and Gardner, W.S., 1986, Response of selected sorghum hybrids to inoculation with MDMV A and B strains. Phytopathology, **76** (10): 1126-1127 (Abst.).
- Choudekar, T.N., Garud, T.B., Mali, V.R. and Choudhari, S.D., 1989, Effect of sorghum red stripe disease on growth and grain yield of rabi sorghum. J. Maharashtra Agril. Univ., **14** (1): 74-77.
- Choudhary, M.M. and Rosenkranz, E., 1983, Vector relationship of Graminella nigrifrons to maize chlorotic dwarf virus. Phytopathology, **73**: 685-690.
- Chu, P.W.G. and Francki, R.I.B., 1982, Detection of lettuce necrotic yellow virus by ELISA in plant and insect vector. Ann. Appl. Biol., **100**: 149-156.
- Clarks, M.F. and Adams, A.N., 1977, Characteristics of the microplate method of enzyme-linked immunosorbent assay for the detection of plant virus. J. Gen. Virol., **34**: 475-483.
- Clark, M.F. and Bar-Joseph, M., 1984, Enzyme linked immunosorbent in plant virology, In: Methods in Virology. K. Maramorosch and H. Koprowski eds. Vol VII Pages 51-85, Academic Press, New York.
- Conti, M., 1980, Vector relationships and other characteristics of barley yellow striate mosaic virus (BYSMV). Ann. Appl. Biol., **95**: 83-92.
- Converse, R.H., Selly, J. and Martin, L.W., 1979, Evidence for random spread of aphid borne yellow edge virus in strawberries. Phytopathology, **69**: 142-144.
- Dabrowski, Z.T., 1985, The biology and behavior of Cicadulina triangula in relation to maize streak virus resistance screening. Insect Sci. Appl., **6**: 417-424.
- Dale, J.L., 1964, Isolation of mechanically transmitted virus from corn in Arkansas. Pl. Dis. Rep., **48**: 661-663.
- Damsteegt, V.D., 1983, Maize streak virus. I. Host range and vulnerability of maize germplasm. Pl. Dis., **67**: 734-737.
- Doggett, H., 1988, The sorghum crop, pages 1-33 In : Sorghum published in Association with the International Development Research Centre, Canada, 512 pp.
- Dinoor, A., 1974, Role of wild and cultivated plants in the epidemiology of plant diseases in Israel. Ann. Rev. Phytopathol., **12**: 413-436.
- Dollet, M., Accotto, G.P., Lisa, V., Menissier, J. and Boccardo, G., 1976, A geminivirus serologically related to maize

- streak virus from Digitaria sanguinalis from Vanuatu. J. Gen. Virology, **67**: 933-937.
- Doodson, J.K. and Saunders, P.J.W., 1970, Some effects of barley yellow dwarf virus on spring and winter cereals in field trials. Ann. Appl. Biol., **66**: 361-374.
- Duffus, J.E., 1971, Role of weeds in the incidence of virus diseases. Ann. Rev. Phytopathol., **9**: 319-340.
- Duffus, J.E. and Skoyen, I.O., 1977, Relationship of age of plant and resistance to severe isolate of the beet curly top virus. Phytopathology, **67**: 151-154.
- Duffus, J.E., 1983, Epidemiology and control of curly top diseases of sugarbeet and other crops. Pages 297-304 in: Plant Virus Epidemiology, R.T. Plumb and J. M. Thresh Eds. Blackwell Scientific Publications, Oxford, London, 377 pp.
- Eagen, B.T., 1965, Chlorotic streak disease. Investigations into host range and possible source of resistance. Proc. Cong. Intl. Soc. of Sugarcane Technol., **17**: 1056-1059.
- Everett, T.R. and Lamey, H.A., 1969, Hoja blanca Pages 361-377. In: Viruses vectors and vegetation. K. Marmamosch, Inter-science, New York.
- Eweida, M., Oxefelt, P and Tomenuis, K., 1988, Concentration of virus and ultrastructural changes in oats at various stages of barley yellow dwarf virus infection. Ann. Appl. Biol., **112**: 313-321.
- Falk, B.W. and Tsai, J.H., 1985, Serological detection and evidence for multiplication of maize mosaic virus in planthopper Peregrinus maidis. Phytopathology, **75**: 852-855.
- Falk, B.W., Tasi, J.H. and Lommel, S.A., 1987, Differences in levels of detection of maize stripe virus capsid and major non capsid proteins in plant and insect hosts. J. Gen. Virol., **68**: 1801-1811.
- Fargette, D., Jenniskens, M.J., Peters, D., 1982, Acquisition and transmission of pea enation mosaic virus by the individual pea aphid. Phytopathology, **72**: 1386-1390.
- Fargette, D., Lister, R.M. and Hood, E.L., 1982, Grasses as reservoir of barley yellow dwarf virus in Indiana. Pl. Dis., **66**: 1041-1045.
- Fazli, S., Toler, R.W. and Bockholt, A.J., 1970, Reaction of selected sorghum and millet hybrid cultivars and accessions to strains of sugarcane mosaic virus and maize dwarf mosaic virus. Phytopathology, **60**: 1291-1292 (Abst.).

- Fesemisin, J.H., Cook, G.E., Okusanya, F. and Shoyinka, S.A., 1976, Maize streak epiphytotic in Nigeria. Pl. Dis. Rep., **60**: 443-447.
- *Ferreira, D.I.C., Garrido, M.J. and Trujillo, G.F., 1989, Maize hoja blanca virus infecting sorghum (Sorghum bicolor (L.) Moench) in Maracay Aragua. Fitopatologia Venezolana, **2** (1): 23-27.
- Francki, R.I.B., Ryan, C.C., Hatta, T., Rohozinski, J. and Grivell, C.J., 1986, Serological detection of Fiji disease virus antigens in the planthopper Perkinsiella sacharicida and its inefficient ability to transmit the virus. Pl. Pathol., **35**: 324-328.
- *Galvez, J.W., Thurston, H.D. and Jennings, P.R., 1961, Host range and insect transmission of the hojablanca disease of rice. Ibid, **45**: 949-953.
- Galvez, G.E., 1968, Transmission studies of the hoja blanca virus with highly active free colonies of Sogatodes oryzicola. Phytopathology, **58**: 818-821.
- Garud, T.B. and Mali, V.R., 1980, Effect of plant age on sorghum red stripe virus disease development and yield of sorghum hybrid. Indian J. Mycol. Pl. Pathol., **24** (Abst.).
- Garud, T.B. and Mali, V.R., 1981, Screening of sorghum germplasm against sorghum red stripe virus. Indian J. Mycol. Pl. Pathol., **11** (1): 94-95.
- Garud, T.B., 1982, Investigations on a red stripe disease of sorghum (Sorghum bicolor (L.) Moench). Ph.D, thesis, Marathwada Agril. Univ., Parbhani, India, 115 pp.
- Garud, T.B. and Mali, V.R., 1983, A red stripe virus disease of sorghum in India. Indian Phytopathol., **36** (3): 545-546.
- Garud, T.B., Mali, V.R., Kohire, O.D. and Choudahri, S.D., 1991, Distribution of sorghum red stripe disease in sorghum planted near to surarcane. J. Maharashtra Agric. Univ., **16** (2): 283.
- Gera, A., Loebenstein, G. and Raccah, B., 1978, Detection of cucumber mosaic virus in viruliferous aphids by ELISA. Virology, **86**: 542-545.
- Gibbs. A.J. and Gower, J.C., 1960, The use of a multiple transfer method in plant virus transmission studies. Some statistical points arising in the analysis of results. Ann. Appl. Biol., **48**: 75-83.
- Gibbs, A.J., 1983, A simple convolution method for describing and comparing the distribution of virus affected plants in a plant community pages. 39-50 in : Plant virus Epidemio-

- logy, R.T. Plumb and J.M. Thresh eds. Blackwell Scientific Publications, Oxford, 377 pp.
- Gildow, F.E. and D'Arcy, C.J., 1988, Barley and oats as reservoir for an aphid virus and the influence on barley yellow dwarf virus transmission. Phytopathology, **78**: 811-816.
- Gingery, R.E., Nault, L.R., Tsai, J.H. and Lastra, R.S., 1979, Occurrence of maize stripe virus in the United States and Venezuela. Pl. Dis. Rep., **63**: 341-343.
- Gingery, R.E., Nault, L.R. and Bradfute, O.E., 1981, Maize stripe virus characteristics of a member of a new virus class. Virology, **112**: 99-108.
- Gingery, R.E., Gordon, D.T. and Nault, L.R., 1982, Purification and properties of maize rayado fino virus from the United States. Phytopathology, **72**: 1313-1318.
- Gingery, R.E., 1983, Maize stripe virus pages 69-74 In: D.T. Gordon, J.K., Knoke, L.R. Nault, and R.M. Ritter eds. Proc. Inter. Maize Virus Disease Colloquium and Workshop 2-6 August 1982. The Ohio State University, Ohio Agricultural Research and Development Centre Wooster, 266 pp.
- Gingery, R.E., 1985, Maize stripe virus, Descriptions of plant viruses No. 300. Association of Applied Biologists, Warwick U.K., 4 pp.
- Gingery, R.E., 1988, The rice stripe virus group In: Milne, R.G (Ed.) The plant viruses Vol IV pp. 297-329. Plenum Publishing Corporation, New York.
- Giorda, L.M. and Toler, R.W., 1985, Use of virus concentration, symptomology and yield as a measure of resistance to MDMV-A in different sorghum cultivars. Phytopathology, **76**: 1072-1073 (Abst.).
- Gorter, G.J.M.A., 1947, Wheat stunt - A new cereal disease. Farm South Africa, **22**: 29-32.
- Gorter, G.J.M.A., 1953, Studies on the spread and control of the streak disease of maize. Union South Africa Sci. Bull., **341**, 20pp.
- Graham, C.L., 1979, Inability of certain vectors in North America to transmit maize streak virus. Environ. Entomol., **8**: 228-230.
- Greber, R.S., 1977, A severe stunting virus disease of maize in Queensland. Aust. Pl. Pathol. Soc. Newsl., **6**: 18.
- Greber, R.S., 1981, Maize stripe disease in Australia. Aust. J. Agric. Res., **32**: 27-36.

- Greber, R.S., 1982, Maize sterile stunt - A delphacid transmitted rhabdovirus disease affecting some maize genotype in Australia. Aust. J. Agric. Res., **33**: 13-23.
- Greber, R.S., 1983, Characteristics of viruses affecting maize in Australia pages 206-218 In: D.T. Gordon, J.K. Knoke, L.R. Nault and R.M. Ritter, eds. Proc. Inter. Maize virus Disease colloquium and workshop 2-6 August 1982. The Ohio State University, Ohio Agric. Res. and Development Centre, Wooster, 266 pp.
- Greber, R.S., 1989, Biological characteristics of grass gemini-viruses from Eastern Australia. Ann. Appl. Biol., **114**: 471-480.
- Gregory, L.V. and Ayers, J.E., 1980, The influence of MDMV on yield of sweet corn. Phytopathology, **70** (5): 463 (Abst.).
- Gunnery, S. and Datta, A., 1987, An inhibitor RNA of translation from barley embryo. Biochem. Biophys. Res. Commun., **142**: 383-388.
- Guthrie, E.J., 1978, Measurement of yield loss caused by maize streak disease. Pl. Dis. Rep., **62**: 839-841.
- Hamilton, R.I., 1965, An embryo test for detecting seed borne barley stripe mosaic virus in barley. Phytopathology, **55**: 788-789.
- Handa, K. and Harrison, B.D., 1977, Effects of genotype and temperature on seed transmission of nepoviruses. Ann. Appl. Biol., **85**: 79-92.
- Henzell, R.G., Persley, D.M., Greber, R.S., Fletcher, D.S. and Van Slobbel, 1982, Development of grain sorghum lines with resistance to sugarcane mosaic virus and other sorghum diseases. Pl. Dis., **66**: 900-901.
- Herd, G.W., 1956, Maize diseases during 1954-55 season. Rhodesian Agric. J., **53**: 525-537.
- Hibino, H. and Kimura, I., 1982, Detection of rice ragged stunt virus in insect vectors by ELISA. Phytopathology, **72**: 656-659.
- Hibino, H., Salch, N. and Roechan, M., 1979, Transmission of two kinds of rice tungro associated viruses by insect vectors. Phytopathology, **69**: 1266-1268.
- Hill, J.H., Martinson, C.A. and Russel, W.A., 1974, Seed transmission of maize mosaic virus and wheat streak mosaic virus in maize and response to inbred lines. Crop Sci., **14**: 232-235.

- Hobbs, H.A., Reddy, D.V.R., Rajeswari, R. and Reddy, A.S., 1987, Use of direct antigen coating and protein A coating ELISA procedure for detection of three peanut viruses. Pl. Dis., **71**: 747-749.
- Hunt, R.F. and Nault, L.R., 1990, Influence on life history of grasses and maize chlorotic dwarf virus on the biotic potential of the leafhopper Graminella nigrifrons (Homoptera : Cicadellidae). Environ. Entomol., **19** (1): 76-84.
- Hurst, G.W., 1965, Forecasting the severity of sugarbeet yellows. Pl. Pathol., **14**: 47-53.
- IITA, 1975a, Survey of disease and insect damage. Annual Report for 1975, 163-164. Ibadan, Nigeria.
- Izadpanah, K., Ahmadi, A.A., Parvin, S. and Jafari, S.A., 1983, Transmission, particle size and additional hosts of the rhabdovirus causing maize mosaic in Shiraz, Iran. Phytopathol. Z., **107**: 283-288.
- Jackson, M.L., 1967, Soil Chemical Analysis. Prentice Hall India, Private Limited, New Delhi, 498 pp.
- Jarjees, M.M. and Uyemoto, J.K., 1983, Maize dwarf mosaic virus: Effect of time of inoculation and symptomology on performance of sorghum. Pl. Dis., **67** (5): 488-489.
- Jennings, R.R., 1963, Estimating yield loss in rice caused by rice hoja blanca. Phytopathology, **53**: 492.
- Jensen, S.G., Palomar, M.K., Ball, E.M. and Samson, R., 1985, Factors influencing virus titre in maize dwarf mosaic infected sorghum. Phytopathology, **75**: 1132-1136.
- Khan, M.A., Hibino, H., Aguiro, V.M., Daquioog, R.D. and Opina, O.S., 1991, Rice and weed hosts of rice tungro associated viruses and leafhopper vectors. Pl. Dis., **75**: 926-930.
- Klassen, V.A. and Falk, B.W., 1989, Characterization of a California isolate of sorghum yellow banding virus. Phytopathology, **79** (6): 646-650.
- Klein, M.I., Greenberger, H.A. and Sela, I., 1973, A mosaic virus disease of maize and sorghum in Israel. Pl. Dis. Rep., **57** (2): 125-128.
- Koenig, R., 1978, ELISA in the study of homologous and heterologous reactions of plant viruses. J. Gen. Virology, **40**: 309-318.
- Kondiah, A., John, V.T. and Reddy, A.P.K., 1976, In vitro isolation of the tungro virus from cut leaves of rice. Intl. Rice Res. Newsl., **1**: 18.

- Kondaiah, A. and John, V.T., 1977, Recovery of rice tungro virus from dried infected leaves. Phytopathol. Z., **90**: 311-314.
- Knoke, J.K., Louie, R., Anderson, R.J. and Gordon, D.T., 1974, Distribution of maize dwarf mosaic virus (MDMV) and aphid vector in Ohio. Phytopathology, **64** : 639-645.
- Knoke, J.K. and Louie, R., 1981, Epiphytology of maize virus diseases pages 92-102 in: Virus and virus like diseases in maize in the United States. D.T. Gordon, J.K. Knoke and G. E. Scott, eds. South Coop. Ser. Bull., 247. 210 pp.
- Knoke, J.K., Anderson, R.J., Louie, R., Madden, L.V. and Findley, W.R., 1983, Insect vectors of maize virus and maize chlorotic dwarf virus. Page 130-138 in Proc. Inter. Maize virus Disease colloquium and workshop 2-6 August 1982.
- *Kitani, K., Kiso, A., 1967, Localization of rice stripe virus antigen in tissue of diseased rice and wheat leaves and viruliferous planthoppers Laodelphax striatellus, by fluorescent antibody technique. Ibid, **33**: 108 (Abst.).
- Kisimoto, R., 1973, Leafhoppers and planthoppers Pages 137-156. In: Viruses and invertebrates. A.J. Gibbs Eds. New York, Elsevier.
- Kiritani, K., 1979, Pest management in rice. Ann. Rev. Entomol., **24**: 279-312.
- Kiritani, K., 1983, Changes in cropping practices and the incidence of hopper borne disease of rice in Japan. Pages 239-247. In: Plant virus epidemiology R.T. Plumb and J.M. Thresh Eds. Blackwell Scientific Publications, Oxford, 377 pp.
- Kulkarni, H.R., 1973, Comparison and characterization of maize stripe and maize line viruses. Ann. Appl. Biol., **75**: 205-216.
- *Kunkel, L.O., 1922, Insect transmission of yellow stripe disease Hawaii Pl. Rec., 26: 58-64.
- Lamey, H.A., McMillian, W.W. and Hendrick, R.D., 1964, Host range of the hoja blanca virus and its vector. Phytopathology, **54**: 536-541.
- Lamey, H.A., Showers, W.B. and Evertt, T.R., 1965, Development stage of rice plant affects susceptibility to hoja blanca virus. Phytopathology, **55**: 1065.
- *Lamey, H.A., 1969, Varietal resistance to hoja blanca in the virus diseases of rice plants. 293-311. Baltimore Maryland Johns Hopkins Press.

- Langham, M.A., Toler, R.W. and Alexander, J.D., 1985, Reaction of sorghum accessions to strains of MDMV A,D, E and O strains in greenhouse screening. Sorghum Newsl., **28**: 102-103.
- Lastra, J.R. and Esparza, J., 1976, Multiplication of vesicular stomatitis virus in the leafhopper Peregrinus maidis (Ashm) a vector of plant rabdovirus. J. Gen. Virol., **32**: 139-142.
- Lastra, J.R., 1977, Maize mosaic and other maize virus and virus like diseases in Venezuela. Pages 30-39. In : D.T. Gordon and Nault, L.R. Eds. Proc. Maize virus diseases colloquium workshop 16-18 August 1976. Ohio Agri. Res. Dev. Centre, Wooster, 145 pp.
- Law, M.D., Mayer, J.W. and Payne, G.A., 1989, Effect of host resistance on pathogenesis of maize dwarf mosaic virus. Phytopathology, **79**: 757-761.
- Lei, J.D. and Agrios, G.N., 1986, Mechanism of resistance in corn to maize dwarf mosaic virus. Phytopathology, **76**: 1034-1040.
- Ling, K.C., Aguiro, V.M. and Lee, S.H., 1970, A mass screening method for testing resistance to grassy stunt disease of rice. Pl. Dis. Rep., **54** (7): 565-569.
- Ling, K.C., Tiogeo, E.R. and Zenaida, M., 1983, Epidemiological studies of rice tungro virus. Pages 249-257 in: Plant virus epidemiology R.T. Plumb and J.M. Thresh Eds. Blackwell Scientific Publications, Oxford, 377 pp.
- Lister, R.M., 1978, Applications of ELISA for detecting viruses in soybean seed and plants. Phytopathology, **68**: 1393-1400.
- Louie, R. and Knoke, J.K., 1991, Detection of maize dwarf mosaic onset in Northern Ohio. Phytopathology, **81**: 760-765.
- Ludwig, J.A. and Reynolds, J.F., 1988, Statistical Ecology. Wiley Interscience Publications, New York, 377 pp.
- Madden, L.V., Louie, R., Abt, J.J. and Knoke, J.K., 1982, Evaluation of tests of randomness of infected plants. Phytopathology, **72**: 195-198.
- Madden, L.V. and Nault, L.R., 1983, Differential pathogenicity of corn stunting mollicutes of leafhopper vectors in Dalbulus and Boldulus species. Phytopathology, **73**: 1608-1614.
- Madden, L.V., Knoke, J.K. and Louie, R., 1986, Effect of source, strength and direction on the spread of maize dwarf mosaic virus. J. Phytopathol., **117**: 92-96.

- Madden, L.V., Knoke, J.K. and Louie, R., 1990, Spread of maize chlorotic dwarf virus in maize fields by its leafhopper Graminella nigrifrons. Phytopathology, **80**: 291-298.
- Mali, V.R. and Bhagwat, V.Y., 1975, Virus and virus like diseases of sorghum in Marathwada. Sorghum Newsl., **18**: 44-45.
- *Managelslorf, P.C., 1974, Corn : Its origin, evolution and improvement. Belknap Press Cambridge 262 pp.
- Maramorosch, K. and Jensen, D.D., 1963, Harmful and beneficial effects of plant viruses in insects. Ann. Rev. Microbiol., **17**: 495-530.
- Maramorosch, K., 1969, Viruses, vectors and vegetation. Interscience Publishers, John Wiley and Sons, New York, 666 pp.
- Maramorsch, K. and Harris, K.F., 1979, Leafhopper vectors and plant diseases agents. New York Academic Press, 654 pp.
- Martin, T.J. and Hackerott, L., 1982, Greenhouse seedling technique to determine the reaction of sorghum to MDMV strain A. Crop Sci., **22**: 1255-1256.
- Mathews, R.E.F., 1971, Plant virology. Academic Press, New York, 788 pp.
- Mathew, S.K. and Basu, A.N., 1986, Relationship of rice grassy stunt virus with its planthopper. Curr. Sci., **55**: 1245-1247.
- Mayhew, D.E. and Flock, R.A., 1981, Sorghum stunt mosaic. Pl. Dis. **65**: 84-86.
- Mauray, Y., Bossennee, J.M., Boudazin, G. and Duby, C., 1983, The potential of ELISA in testing soybean mosaic virus. In : Abstracts of Intl. Working Group of legume viruses. No. 8, Queensland, Australia.
- McClean, A.P.D., 1947, Some forms of streak virus occurring in maize, sugarcane and wild grasses. Science Bulletin Dept. Agric. and for. Union of South Africa No. 265, 39 pp.
- McClean, G.D., Garret, R.G. and Ruesink, W.G., 1986, Plant virus epidemics. Academic Press, New York, 550 pp.
- McEven, F.L. and Kawanishi, C.Y., 1967, Insect transmission of corn mosaic. Laboratory studies in the Hawaii. J. Econ. Entomol., **60**: 1413-1417.
- Migliori, A. and Lastra, R, 1980, Study of a virus type disease present in Guadeloupe and transmitted by Perigrinus maidis Annales de Phytopathologie, **12(3)**: 277-294.

- Mikel, M.A., D'Arey, C.J., Rhodes, A.M. and Ford, R.E., 1980, Yield loss in sweet corn correlated with time of inoculation with maize dwarf mosaic virus. Pl. Dis., **65**: 902-904.
- Miller, P.R., 1966, Index of plant virus diseases. U.S. Department of Agriculture Handbook No. 307. Washington, DC, USA.
- Moline, H.E., 1973, Mechanically transmissible viruses from corn and sorghum in South Dakota. Pl. Dis. Rep., **57** (4): 373-374.
- Morales, F.J. and Niessen, A.I., 1985, Rice hoja blanca virus. In: Descriptions of plant viruses No. 199. Association of Applied biologists, National Vegetable Research Station, Wellesbourne Warwick, U.K.
- Mote, U.N., 1983, Epidemic of delphacids and aphids of winter sorghum. Sorghum Newsl., **26**: 76.
- Mumford, D.L., 1982, Using ELISA to identify beet leafhopper populations causing beet curly top virus. Pl. Dis., **60**: 940-941.
- Nagaraju and Viswanath, S., 1981, Studies on the relationship of ragi streak virus and its vector Cicadulina chinai. Indian Phytopathol., **34** (4): 458-460.
- Nagaraju, Viswanath, S., Lucy Channamma, K.A. and Reddy, H.R., 1981, Effect of virus on growth and yield of ragi. Indian Phytopathol., **34**: 356-358.
- Nagaraju, Viswanath, S., Reddy, H.R. and Lucy Channamma, 1982, Ragi streak. A leafhopper transmitted virus disease in Karnataka. Mysore J. Agric. Sci., **16**: 301-305.
- Naidu, R.A., Harikrishna, R., Manohar, S.K., Reddy, D.V.R., Ratna, A.S., King, S.B. and Bandyopadhyay, R., 1989, Maize mosaic virus on sorghum. Ann. Appl. Biol., **114**: 301-310.
- Narayanaswamy, P., 1972, Influence of age of rice plants at the time of inoculation on the recovery of tungro virus by Nephotettix impicticeps. Phytopathol. Z., **74**: 109-114.
- Narros, J., Berger, P.H. and Toler, R.W., 1983, Sorghum viruses in Mexico. Phytopathology, **73** (3): 504 (Abst.).
- Nault, L.R., 1982, Origin of leafhopper vectors, maize viruses and mycoplasma in Mesoamerica. In: Plant virus epidemiology, Eds, R.T.Plumb, J.M. Thresh, Blackwell Publication, London.
- Nault, L.R., Gordon, D.T., Robertson, D.C. and Bradfute, O.E., 1976, Host range of maize chlorotic dwarf virus. Pl. Dis. Rep., **60**: 374-377.

- Nault, L.R., Gordon, D.T., Gingery, R.F., Bradfute, O.F. and Castillo-Loayza, J., 1979, Identification of maize viruses and mollicutes and their potential insect vectors from Peru. Phytopathology, 824-828.
- Nault, L.R., Gingery, R.E. and Gordon, D.T., 1980, Leaf hopper transmission and host range of maize rayado fino virus. Phytopathology, 70: 709-712.
- Nault, L.R. and Madden, L.V., 1985, Ecological strategies of Dalbulus leafhoppers. Ecol. Entomol., 10: 57-63.
- Nault, L.R. and Rodriguez, J.G., 1985, The leafhopper and planthoppers. New York, Wiley.
- Nault, L.R. and Gordon, D.T., 1988, Multiplication of maize stripe virus in Peregrinus maidis. Phytopathology, 78: 991-995.
- Nault, L.R. and Ammar, E.D., 1989, Leafhopper and planthopper transmission of plant viruses. Ann. Rev. Entomol., 34: 503-529.
- Nelson, M.W., 1985, Leafhopper systematics. Pages 11-39, In: Marmorosch, K. and Harris, K.F. Eds. Leafhoppers vectors and plant disease agents. New York, Academic Press.
- Nishida, T., 1978, Management of the corn planthopper in Hawaii. FAO Pl. Prot. Bull., 26 (1): 5-9.
- Ofori, F.A. and Francki, R.I.B., 1985, Transmission of leafhopper and virus, vertically through eggs and horizontally through maize in which it does not multiply. Virology, 144: 152-157.
- Oswald, J.W. and Huston, B.R., 1953, Host range and epiphytology of the cereal yellow dwarf virus. Phytopathology, 50: 309-313.
- Ou, S.H., 1985, Stripe, Pages 13-19; In : Rice Diseases. 2nd Edition, CAB, Kew, Surrey, England, 380 pp.
- Ou, S.H., 1985, Hoja blanca. Pages 26-30, Rice Diseases 2nd Edition, Common Wealth Mycological Institute, Surrey, U.K., 380 pp.
- Paliwal, Y.C., Raychaudhuri, S.P. and Renfro, B.L., 1968, Some properties and behaviour of maize mosaic virus. Phytopathology, 58: 1682-1684.
- Pande, S., Alebejo, M.D., 1990, Survey of sorghum virus and other diseases in Nigeria. Tour Report 16th Sept. 1990 to 22nd Oct. 1990. ICRISAT (RP 06512) 48 p.

- Pawar, P.S., Garud, T.B., Mali, V.R. and Chouduri, S.D., 1990, Effect of sorghum red stripe virus on leaf chlorophyll and sugar content in stalk juice in different genotypes of sorghum. Indian Phytopathol., **43** (3): 345-348.
- Penrose, L.J., 1974, Distribution of a johnsongrass strain of SCMV in New South Wales and studies of the host range of the johnsongrass and sugarcane strains. Aust. J. Agric. Res., **25**: 99-104.
- Peterschmitt, M., Ratna, A.S., Sacks, W.R., Reddy, D.V.R., and Mughogho, L.K.M., 1991, Occurrence of an isolate of maize stripe on sorghum in India. Ann. Appl. Biol., **118** (1): 57-70.
- Persley, D.M. and Greber, R.S., 1982, The reaction of sorghum genotypes to natural infection by sugarcane mosaic virus johnsongrass strain of Australia. Sorghum Newsl., **25**: 105.
- Pitre, H.N. and Hepner, L.W., 1967, Seasonal incidence of indigenous leafhoppers (Homoptera : Cicadellidae) on corn and several winter crops in Mississippi. Ann. Entomol. Soc. Am., **60** (5): 1044-1055.
- Plumb, R.T. and Thresh, J.M., 1983, Plant virus epidemiology. Blackwell Scientific Publications, Oxford, London, 377 pp.
- Pinner, M.S., Markham, P.G., Marktam, R.H. and Dekker, R.L., 1988, Characterization of maize streak virus, description of strains, symptoms. Pl. Pathol., **37**: 74-87.
- Prabhakar, B., Rao, P.K. and Rao, B.H.K., 1986, Studies on the seasonal prevalence of certain Hemiptera occurring on sorghum. Entamon, **11** (2): 95-99.
- Prasad Rao, R.D.V. J. and John V.T., 1974, Alternate hosts of rice tungro virus and its vector. Pl. Dis. Rep., **58**: 856-860.
- Purcell, A.H., 1982, Evolution of the insect-vector relationship. In: Phytopathogenic prokaryotes. Pages 121-156 edx. M.S. Mount and G.H. Lacey, New York, Academic Press.
- Raga, I.N., Ito, K., Matsui, M. and Okada, M., 1988, Effect of temperature on adult longevity, fertility and rate of transovarial passage of rice stripe virus in the planthopper Laodelphax striatellus (Homoptera : Delphacidae). Appl. Entomol. Zool., **23**: 67-75.
- Rawat, R.R. and Saxena, D.K., 1967, Studies on the bionomics of Peregrinus maidis (Ashmead) (Homoptera : Araeopidae). JNKVV Res. J., **1**: 64-67.

- Reddy, D.V.R. and Black, L.M., 1972, Increase of wound tumor virus in leafhoppers as assayed in vector cell monolayers. Virology, **50**: 412-421.
- Reeves, J.T., Jackson, A.O., Paschke, J.D. and Lister, R.M., 1978, Use of ELISA for serodiagnosis of two maize viruses. Pl. Dis. Rep., **62**: 667-671.
- Roane, C.W. and Tolin, S.A., 1969, Distribution and host range of maize dwarf mosaic virus in Virginia. Pl. Dis. Rep., **53** (4): 307-310.
- Roca, de Doyle, M.M. and Autrey, L.J.C., 1992, Assessment of yield losses as a result of coinfection by maize streak virus and maize stripe virus in Mauritius. Ann. Appl. Biol., **120**: 443-450.
- Roca de Doyle, M.M., Autrey, L.J.C. and Jones, P., 1992, Purification, characterization and serological properties of two virus isolates associated with the maize stripe disease in Mauritius. Pl. Pathol., **41**: 325-334.
- Rochow, W.F., 1970, Barley yellow dwarf viruses. No. 32. In: Descriptions of plant viruses, Kew, Surrey, U.K., CMI, 4 pp.
- Rodrigo Gamez, 1983, The ecology of maize rayado fino virus in the American tropics, Pages 267-275. In: Plant virus epidemiology. R.T. Plumb, J.M. Thresh eds., Blackwell Scientific Publication, Oxford, 377 pp.
- Rose, D.J.W., 1972, Dispersal and quality in populations of *Cicadulina*. J. Ani. Ecol., **41**: 589-609.
- Rose, D.J.W., 1974, The epidemiology of maize streak disease in relation to population densities of *Cicadulina* spp. Ann. Appl. Biol., **76**: 199-207.
- Rose, D.J.W., 1978, Epidemiology of maize streak disease. Ann. Rev. Entomol., **23**: 259-282.
- Rosenkranz, E. and Scott, G.E., 1978, Effect of plant age at time of inoculation with maize dwarf mosaic virus on disease development and yield of corn. Phytopathology, **68**: 1688-1692.
- Rosenberg, L.J. and Magor, J.I., 1983, A technique for examining the long distance spread of plant virus diseases transmitted by the brown planthopper *Nilaparvatha lugens* (Homoptera : Delphacidae) and other wind borne insect vectors. Pages 229-247 in: Plant virus Epidemiology R.T. Plumb and J.M. Thresh eds., Blackwell Scientific Publications, Oxford, 377 pp.
- Rosenow, D.T., 1992, Using germplasm collection from the world collection in breeding for disease resistance, Pages 319-

314. In: Sorghum and millet diseases - A second world review (W.A.J. de Milliano, R.A. Frederiksen, and G.D. Bengston eds.). ICRISAT, Patancheru, Andhra Pradesh, India.
- Rossel, H.W. and Thottapilly, G., 1985, Maize virology. In: Annual Report, IITA 1984, Ibaden, Nigeria, 52-53.
- Ruppel, R.I., 1965, A review of the genus *Cicadulina*. Publ. Mich. State Univ., MUS. Biol. Ser., 2: 385-428.
- Saito, Y. and Iwata, Y., 1964, Hemagglutination test for titration of plant viruses. Virology, 22: 426-428.
- *Sakurai, Y. and Ezuka, A., 1964, A seedling test method of varietal resistance in rice plants to stripe virus disease 2. The resistance of various varieties and strains of rice plant by the method of seedling test. Bull. of the chugoku Agric. Expt. Sta. A-10. 51-70.
- Scheifele, G.L., 1969, Effects of early and late inoculation of maize dwarf mosaic virus strain A and B on shelled grain yields of susceptible and resistant maize segregates of three way hybrid. Pl. Dis. Rep., 53 (5): 345-347.
- Seifers, D.L. and Caceres, J., 1988, Titer variation in infected sorghum differing in resistance to maize dwarf mosaic virus strain-B. Phytopathology, 78 (2): 208-212.
- Seth, M.L., Raychaudhuri, S.P. and Singh, D.V., 1971, A streak disease of bajra (Pennisetum typhoides Burmf) Stalf & Hubb) in India. Curr. Sci., 40: 272-273.
- Seth, M.L., Raychaudhuri, S.P. and Singh, D.V., 1972, Bajra (pearl millet) streak : a leafhopper borne cereal virus in India. Pl. Dis. Rep., 56: 424-428.
- Sharma, R.C. and Payak, M.M., 1983, An overview of virus and virus like diseases of maize in India. Pages 186-190. In: D.T. Gordon, J.K. Knoke, Nault, L.R and R.M. Ritter, eds., Proc. Inter. Maize Virus Disease Colloquim and Workshop, 2-6 August. 1982. The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, 266 pp.
- *Shinkai, A., 1956, Host range of rice stripe disease. Ann. Phytopathol. Soc. Japan, 21: 47.
- *Shinkai, A., 1962, Studies on insect transmission of rice virus diseases in Japan. Bulletin of the National Institute of Agril. Sci., Tokyo, 14: 1-112 (J, en).
- Showers, W.R. and Everett, T.R., 1967, Transovarial acquisition of hoja blanca virus by the rice delphacid. J. Econ. Entomol. 60: 757-760.

- 71
- *Signoret, P.A., Conti, M., Leclant, F., Alliot, B. and Giannotti, 1977, Donnees nouvelles sur, le maladie des stries chlorotiques double (wheat chlorotic streak mosaic virus WCSMV). Annales de Phytopathologie, **9**: 381-385.
- Singh, B.U. and Rana, B.S., 1992, Stability of resistance to corn planthopper, Peregrinus maidis (Ashmead) in sorghum germplasm. Insect Sci. Applic., **13**: 251-263.
- Sinha, R.C., 1963, Effect of age of the vector and of abdominal punctures on virus transmission. Phytopathology, **53**: 1170-1173.
- Sinha, R.C., 1973, Viruses and leafhoppers, Pages 493-511. In Viruses and Invertebrates. A.J. Gibbs ed. New York Elsevier.
- Slykhuis, J.T. and Watson, M.A., 1958, Striate mosaic of cereal in Europe and its transmission by Delphacides pellucida Ann. Appl. Biol., **46**: 542.
- Slykhuis, J.T., 1967, Virus diseases of cereals. Rev. Appl. Mycol., **46** (8): 401-429.
- Sogawa, K., 1976, Rice tungro virus and its vector in tropical Asia. Rev. Pl. Prot. Res., **9**: 21-46.
- Soto, P.E., Buddenhagen, I.W. and Asnani, V.L., 1982, Development of streak virus resistant maize populations through improved challenge and selection methods. Ann. Appl. Biol., **100**: 539-546.
- Storey, H., 1928, Transmission studies of maize streak disease Ann. Appl. Biol., **15**: 1-25.
- Storey, H.H., 1936, Virus diseases of East African Plants. V. Streak disease of maize. East Africa Agric. J., **1**: 471-475.
- Sudarshana, M.R. and Reddy, D.V.R., 1989, Penicillinase based enzyme linked immunosorbent assay for the detection of plant viruses. J. Virol Methods, **26**: 45-52.
- *Sugiyama, M., 1966, Studies on the methods of forecasting rice stripe disease. I. Kinds of indicator plants. Ibid, **32**: 83.
- Sum, I., Nemeth, M. and Pacsa, A.S., 1979, Detection of maize dwarf mosaic virus with ELISA. Phytopathol. Z., **95**: 274-278.
- *Sutic, D. and Tosic, M., 1966, A significant occurrence of maize mosaic virus on johnsongrass (Sorghum halepense) as a natural host. Rev. Roum. Biol. Ser. Bot., **11**: 219-224.

- Sylvester, E.S. and Richardson, J., 1969, Additional evidence multiplication of the sowthistle yellow vein virus in aphid vector serial passage. Virology, **37**: 26-31.
- Sylvester, E.S., Richardson, J. and Frazier, N.W., 1974, Serial passage of strawberry crinkle virus in the aphid Chaetosiphon jacobi. Virology, **59**: 301-306.
- Takashi, Y., Omura, T., Shohara, K. and Tsuchizaki, T., 1991, Comparison of four serological methods for practical detection of ten viruses of rice in plants and insects. Pl. Dis., **75** (5): 458-461.
- Tarr, S.A.J., 1962, Disease of sorghum sudangrass and broom corn. Oxford, Oxford Univ. Press, 380 pp.
- Teakle, D.S., 1979, The cause and control of sorghum virus diseases in Australia. Pages 409-413 in: Sorghum diseases A world Review R.J. Williams, R.A. Frederikson, and L.K. Mughogho, ICRISAT, Patancheru, Andhra Pradesh, India.
- Theu, M.P.K.J. and Toler, R.W., 1989, Effect of sorghum yellow banding virus on yield of sorghum accessions. Sorghum Newsl., **31**: 88.
- Thresh, J.M., 1974, Temporal pattern of virus spread, Ann. Rev. Phytopathol., **12**: 111-128.
- Thresh, J.M., 1982, Cropping practices and virus spread. Ann. Rev. Phytopathol., **20**: 193-218.
- Thresh, J.M., 1988b, Eradication : as a virus disease control In : Control of plant disease costs and benefits. (C.B. Clifford and Eilester eds.) Pages 155-194, Blackwell Oxford, London.
- Timian, R.G., 1967, Barley stripe virus seed transmission and barley yield as influenced by time of infection. Phytopathology, **57**: 1375-1377.
- Toler, R.W., 1977, A decade of research on viruses of sorghum pages 54-55. In : Proc. Biann. Grain Sorghum Res. Util. Conf.
- Toler, R.W., 1979, Virus and virus like diseases of sorghum pages 395-408. In: sorghum diseases A world Review R.J. Williams, R.A. Frederikson, and L.K. Mughogho eds. ICRISAT, Patancheru, Andhra Pradesh, India.
- Toler, R.W., 1985, Maize dwarf mosaic, the most important virus disease of sorghum. Pl. Dis., **69**: 1011-1015.
- Toler, R.W. and Giorda, L.M., 1992, Detection and identification of viruses and virus diseases of sorghum pages 153-159 in: Sorghum and Millet Diseases, a second world review. (ed

- Milliano, W.A.J., Fredeviksen, R.A. and Bengston, G.I. (eds.) ICRISAT, Patancheru, Andhra Pradesh, India.
- Tomlinson, J.A. and Walker, V.M., 1973, Further studies on seed transmission in the ecology of some aphids transmitting viruses. Ann. Appl. Biol., **73**: 293-298.
- Toriyama, S., 1983, Rice stripe virus, CMI/AAB Descriptions of plant viruses No. 269.
- Torrance, L. and Jones, R.A.C., 1981, Recent developments in serological methods suited for use in routine testing for plant viruses. Plant Pathology, **30**: 1-24.
- Tosic, M. and Sutic, D., 1977, Investigations of maize mosaic virus transmission through seed. Ann. Phytopathol., **9**: 403-405.
- Tosic, M., 1983, Investigations of maize mosaic in Yugoslavia. Pages 117-121. In: D.T. Gordon, J.K. Knoke, L.R. Naul and R.M. Litter eds. Proc. International Maize virus Disease colloquium and workshop, 2-6 August, 1982. The Ohio State University, 266 pp.
- Trujillo, G.E., Acosta, J.M. and Pinero, A., 1974, A new corn disease found in Venezuela. Pl. Dis. Rep., **58** (2): 122-126.
- *Trujillo, G.E., Guevara, Y. and Colina, R., 1978, Peregrinus maidis (Ashm.) vector of viral diseases of maize. Revista de la Facultad de Agronomia Universidad Central de Venezuela, **9** (4): 51-61.
- Tsai, J.H., 1975, Occurrence of a corn disease in Florida transmitted by Peregrinus maidis. Pl. Dis. Rep., **59**: 830-833.
- Tsai, J.H. and Zitter, T.A., 1982, Characteristics of maize stripe virus transmission by the corn delphacid. J. Econ. Entomol., **75**: 397-400.
- Vann, S.R. and Toler, R.W., 1985, Greenhouse and field screening of sudangrass accessions for resistance to MDMV-strain A&B. Phytopathology, **75**: 1337 (Abst.).
- Van Rensberg, G.D.J., 1981, Effect of plant age at the time of infection with maize streak virus on yield of maize. Phytophylactica, **13**: 197-198.
- Varma, A., Krishnareddy, M. and Malathi, V.G., 1992, Influence of the amount of blackgram mottle virus in different tissues on transmission through seeds of Vigna mungo. Plant Pathology, **41**: 274-281.
- *Varon de Agudello, F. and Martinez Lopez, G., 1982, Preliminary observations on the transmission of virus by Peregrinus.

- maidis. Revista Colombiana de Entomologica, 6 (3/4): 69-76.
- Vidaao, C., Lovisolo, O and Conti, M., 1966, Transmission d virus del Nanismo ruvido del mais (MEDV) a Tritic vulgaris L. per Mezzo de Laodelphax striatella Fall. Aca Sci. torino, 100: 125-140, Torino, Italy.
- Voller, A., Bartlett, A., Bidwell, D.E., Clark, M.T. and Adam A.N., 1976a, The detection of viruses by enzyme-linked immunosorbent assay (ELISA). J. Gen. Virol., 33: 165-167
- Vyavahare, V.M., Garud, T.B. and Mali, V.R., 1989, Effect of sorghum red stripe virus on sorghum genotypes. Indian Phytopathology, 42 (1): 16-20.
- Watson, M.A., 1966, The relation of annual incidence of beet yellowing viruses in sugarbeet to variation in weather. Pl. Pathol., 15: 145-149.
- Watson, L. and Gibbs, A.J., 1974, Taxonomic patterns on the host range of viruses among grasses and suggestions on genetic sampling for host range studies. Ann. Appl. Biol., 71: 23-32.
- *Wallace, J.H. and Murphy, A.M., 1938, Studies on epidemiology of curly top in Southern Idaho with special reference to sugarbeets and weed hosts of the vector Eutettix tenellus. U.S. Dept. Agric. Tech. Bull., 624 : 1-47.
- Wellman, F.L., 1934a, Infection of Zea mays and various other gramineae by the celery virus in Florida. Phytopathology 24: 1035-1037.
- *Yamada, W. and Yamamoto, H., 1956, Studies on the rice stripe disease of rice plant. 1. On the virus transmission by Delphacodes striatella. II. Host plants, incubation period of the virus in the insect vector. Special Bulletin Okayama Prefectural Agric. Expt. Sta., 55: 35-36.
- Yamaguchi, T., 1966, Ecological and physiological studies on the dynamics of the migratory population of rice planthoppers and leafhoppers. Journal of the Central Agricultural Experiment Station, 8: 109-160 (Japanese).
- *Yoshimeki, M., 1966, Ecological and physiological studies on the dynamics of the migratory population of rice planthopper and leafhoppers. Bull. Kyushu Agric. Expt. Sta., 12: 1-78.
- Zeigler, R., Rubiano, M. and Pineda, A., 1988, A field screening method to evaluate rice breeding lines for resistance to hoja blanca virus. Ann. Appl. Biol., 112: 151-158.
- Zeigler, R.S. and Morales, F.J., 1990, Genetic determination of replication of rice hoja blanca virus in its planthopper vector Sogatodes oryzicola. Phytopathology, 80: 559-566.

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- Zhou, Guang-he and Rochow, W.F., 1984, Differences among five species of Schizaphis graminum in transmission of a barley yellow dwarf virus luteovirus. Phytopathology, **74** : 1450 - 1453.
- Zummo, N. and Gordon, D.T., 1971, Comparative study of five mosaic virus isolates infection of corn, johnsongrass and sorghum in the United States. Phytopathology, **61** (4): 389-394.
- Zhu, F.C., Chen, Y.T., Zhang, H.F. and Tsai, J.H., 1983, Identification, transmission, host range and epidemiology of maize dwarf mosaic virus in North Western China. Pages 194-202 in D.T. Gordon, J.K. Knoke, Nault, L.R and R.H. Ritter, eds., Proc. Inter. Maize Virus Disease Colloquium and Workshop, 2-6 August. 1982. The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, 266 pp.

* Originals not seen