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# Yellow leaf disease in sugarcane: A review

**NV Naidu, SJ Mallikarjuna and N Sabitha**

**Abstract**
Sugarcane yellow leaf virus, has been identified as the causative virus of the disease ScYLV, which spreads through vegetative cuttings and one aphid species *viz*., *Melanaphis sacchari*. Sugarcane yellow leaf virus (ScYLV), a phloem-limiting virus belonging to family *Luteoviridae* and genus *Polerovirus*. In India, the occurrence of YL were reported all over the country and susceptible cultivars in commercial fields reach up to 100%. The most characteristic symptom of YLD is a distinct yellowing of the lower surface of the leaf midrib on young leaves at the apex of the mature plants, which can extend laterally to the leaf lamina. The yellowing of the midrib may turn pink or have a reddish tinge. Older leaves show a red coloration of the midrib on the adaxial surface. The leaf blade becomes bleached, proceeding from the tip toward the base of the leaf, and tissue necrosis can eventually take place. The yellowing can spread into the leaf blade and mid-veins can turn pink in severely infected plants. A serological method of detection is the most common since it is rapid, inexpensive and robust. RT-PCR can be rapidly implemented in independent laboratories after the basic protocol and primer sequences are made available. RT-PCR was the first technique developed to diagnose the presence of a virus in symptomatic plants with primers specific to luteoviruses. Variation in pathogenicity among genotypes of ScYLV *viz*., BRA (Brazil), CHN1 and CHN3 (China), CUB (Cuba), HAW (Hawaii), IND (India), PER (Peru), and REU (Re´union Island) has also been reported. Sugarcane yellow leaf virus (ScYLV), naturally infects at least three plant species: sugarcane (*Saccharum* spp.), the weed Columbus grass (*Sorghum almum*) and cultivated sorghum (*Sorghum bicolor*). All three hosts are also colonized by the sugarcane aphid (*Melanaphis sacchari*), the main vector of ScYLV worldwide. No single method is efficient/available to control YLD and hence an integrated approach involving cultural, chemical, physical methods, host resistance and legislative measures may be adopted for the sustainable management of sugarcane diseases.

**Keywords:** Sugarcane, yellow leaf disease, yellow leaf virus, yellowing of midrib, aphids

## 1. Introduction
Sugarcane (genus: *Saccharum*) is a member of the family *Poaceae*. Sugarcane (*Saccharum* interspecific hybrids) is considered as the industrially significant crop. It is one of the most important commercial crops grown mainly for sugar in many countries and also for bio-energy production from its by-products such as, bagasse and molasses. Sugarcane is a very useful asset for economic developments in different tropical and subtropical areas of the globe including India. Sugarcane is grown on 260 million-hectare area in more than 90 countries across the globe. It is one of the world's most important crops, ranking first in production quantity and sixth in net production value in 2016 (FAOSTAT, 2020) [30]. It is by far the most relevant sugar crop, accounting for approximately 80% of the world's sugar production (FAOSTAT, 2020 and ISO, 2020) [30] and is also a prominent energy crop. Sugarcane is one of the important cash crops in India and plays pivotal role in both agricultural and industrial economy. India ranks first in the world with an area of 4.73 million hectares having 2.46% share of total area with a production of 376.9 million tonnes (FAOSTAT, 2020) [30].

## 2. Diseases Affecting Sugarcane
More than 100 diseases on sugarcane have been recorded in India caused by diverse group of pathogens such as fungi, bacteria, virus and phytoplasma (Rao *et al*., 2002; Rott *et al*., 2000; Shailbala and Amarenderkumar, 2016; Bharathi and Sudhakar, 2012 and Rakesh Kumar *et al*., 2015) [59, 61, 63, 70, 10, 57]. A conservative estimate of losses due to diseases in total sugarcane production ranges from 10-25% in terms of yield and juice quality. Maximum damage is caused by sett transmissible diseases. The damage caused to sugarcane during each epidemic would vary depend upon the nature of disease and spread of the affected varieties. Among viral diseases *viz*., s*ugarcane yellow leaf virus* (ScYLV) inducing yellow leaf disease (YLD),

*sugarcane streak virus* (ScSV) responsible for causing streak disease, *sugarcane fiji disease virus* (ScFDV) causing infamous fiji disease, *sugarcane bacilliform virus* (ScBV) known to induce fleck leaf disease (Braithwaite *et al*., 1995) [11] and *sugarcane streak mosaic virus* (ScSMV) and *sugarcane mosaic virus* (ScMV) (Rott *et al*., 2000; Viswanathan and Rao, 2011) [63, 92] are associated with mosaic disease. Long duration of the crop, vegetative propagation, monoculture and practice of ratooning makes sugarcane easily prone to quick build up of the diseases leading reduction in varietal potential which is referred to as varietal degeneration. The disease is reported worldwide in more than 30 countries [Lockhart *et al*. 2000 and Schenck, 2001] [48, 69]. Currently severe disease incidence is observed in all the sugarcane growing states in India. Yellow leaf disease was originally called yellow leaf syndrome of sugarcane (YLS) is commonly observed during 6 to 8 months stages of the crop. YLD on sugarcane was observed in more than 30 countries in the world where sugarcane is widely cultivated. Yellow leaf syndrome is prevalent in almost all parts of the India.

## 3. Occurance of Yld

Yellow leaf disease (YLD) of sugarcane was first reported in Hamakua (Hawaii) on variety H65-0782 in 1989 as yellow leaf syndrome (Schenck, 1990 and Schenck *et al*., 1997) [66, 67] and subsequently from the United States mainland (Comstock *et al*. 1994) [16] yellow leaf syndrome of sugarcane (*Saccharum* L. interspecific hybrids) has been reported from Hawaii (Schenck, 1990) [66], Brazil, continental USA (Comstock *et al*., 1994) [16], Australia (Smith *et al*., 1995) [75], Mauritius (Anon., 1995) [4] and South Africa (Bailey *et al*., 1996) [7] and many other sugarcane growing countries (Abu Ahmad *et al*. 2006 [2]; Arocha *et al*. 1999 [5]; Avila *et al*. 2001 [6]; Bailey *et al*. 1996 [7]; Comstock *et al*. 1998 [15]; Comstock *et al*. 1994 [16]; Comstock *et al*. 2002 [18]; ElSayed and Komor, 2012 [25]; Moutia and Saumtally, 1999 [52]; Rassaby *et al*. 2004 [62]; Smith *et al*. 2000 [74, 76]; Vega *et al*. 1997 [79] and Viswanathan *et al*. 2008] [81]. YLD is reported worldwide in more than 30 countries (Lockhart and Cronje, 2000, Tran-Nguyen *et al*., 2000 [78] and Schenck, 2001) [48, 78, 69]. In India, Viswanathan *et al*. (1999) [91] reported the disease for the first time and the associated *sugarcane yellow leaf virus* which assumed its severity on different sugarcane varieties. Rao *et al*. (2000, 2001) [60] and Viswanathan (2002) [84] reported further spread of YLD in sugarcane in different regions. In India, the disease is prevalent in major sugarcane growing states like Andhra Pradesh, Karnataka, Tamilnadu and Madhya Pradesh (Viswanthan, 2002; Suresh *et al*., 2014 and Viswanathan and Rao, 2011) [84, 77, 92]. Yellow Leaf Disease (YLD) posing serious problems during the recent past and severe losses reported in several sugarcane growing regions of both Andhra Pradesh and Teangana states (Rajakumar *et al*., 2012) [56]. Viswanathan *et al*. (2006) [87] established that disease and the associated virus (ScYLV) in infected setts are the primary source for the disease in the field. They found that the disease incidence was more severe in ratoons and in poorly maintained fields. Viswanathan and Balamuralikrishnan (2004) [83] found that RSD infection in sugarcane varieties favours severity of YLD. The incidence of ScYLV in commercial fields can reach 100% in susceptible cultivars and the disease can cause significant yield losses in susceptible cultivars even if infected plants do not exhibit the disease symptoms.

## 4. Impact of Yld on cane yield and quality

ScYLV is considered to be the most important viral disease of sugarcane worldwide that can cause significant yield losses. ScYLV infection reduced plant growth and juice yield by 39-43% and 30-34%, respectively, in susceptible varieties at harvest in India (Viswanathan *et al*. 2014) [82].

The disease infection results in reduction in cane diameter, HR brix and photosynthetic rate in leaves of infected sugarcane varieties as compared to the respective disease free set of sugarcane varieties (Viswanathan, 2002) [84]. Drastic reduction in NMC was recorded due to disease infection (Viswanathan *et al*. 2006) [87]. The recent studies in India very clearly established that ScYLV infection causes 42.9, 42.3 and 38.9% reductions in plant growth in susceptible cvs CoPant 84211, Co 86032 and CoC 671, respectively. Also, losses of 34.15, 31.17 and 30.26% in juice yield during crop maturity stage were recorded respectively in susceptible cvs CoPant 84211, Co 86032 and CoV 92101 in India (Viswanathan *et al*. 2014) [82].

The highest yield loss (50%) was reported due to ScYLV in ratoon crops (Grisham *et al*., 2001 and Vega *et al*., 1997) [35, 79]. Up to 14% loss in sugar yield was described in Louisiana (Gonçalves *et al*., 2005 and Grisham *et al*., 2001) [35]. In Florida, 11% loss was recorded in sugar yield and stalk weight (Comstock and Miller, 2004) [17], 14% loss in sugar yield (Flynn *et al*., 2005) [32] and 11% to 27% in sugarcane yield were reported in different experimental fields (Boukari *et al*., 2019) [94]. In Reunion of Island, 11% and 28% losses were documented in sugar content and stalk weight, respectively due to virus infection (Rassaby *et al*., 2004) [62]. Around 30% loss in yield was stated in asymptomatic sugarcane plants in Thailand (Lehrer *et al*., 2008) [46]. Viswanathan *et al*. (2014) [82] studied the negative effect of ScYLV, reduction in different parameters including 24% in photosynthetic rate, 28% in stomatal conductance, 10% in chlorophyll content, 10% in chlorophyll-fluorescence ratio, 10% in length of the internodes, 15% in girth of the stalk, 28% in stalk weight, up to 44% in leaf sheath weight and 39% in juice yield while, increasing the levels of carbohydrates and transpiration rate by 81% and 16%, respectively in virus infected leaves.

## 5. Causal Organism

Yellow leaf disease (YLD) or yellow leaf syndrome (YLD) was first described in Hawaii (Schenck, 1990) [66] when plantation fields of sugarcane (*Saccharum officinarum*) cv. H 65-7052 expressed severe yellowing. A virus was isolated from infected plants which was identified as a member of the *Luteoviridae* and named *Sugarcane yellow leaf virus* (ScYLV) (Scagliusi and Lockhart, 2000) [65]. Sugarcane yellow leaf virus is a *Polerovirus* (Family Luteoviridae) evolved by recombination between the ancestors of *Luteovirus*, *Polerovirus* and *Enamovirus* (Moonan *et al*., 2000 and Smith *et al*., 2000) [37, 74, 76]. Recently, complete genome of ScYLV-IND genotype was reported from India (Chinnaraja *et al*. 2013) [13]. The *luteovirus sugarcane yellow leaf virus* (ScYLV) was identified as causal agent of the disease (Scagliusi and Lockhart, 2000) [65]. Tissue blot immunoassays and/or PCR (Schenck *et al*. 1997 and Korimbocus *et al*. 2002) [67, 43] tests revealed that ScYLV occurred worldwide. The worldwide distribution most likely proceeded through germplasm exchange and it depended very much on whether the imported germplasm was susceptible to

and infected by ScYLV. Spread of ScYLV usually occurs by vegetative propagation of infected stem pieces.

**6. Symptoms of Yld**

The most characteristic symptom of YLD is a distinct yellowing of the lower surface of the leaf midrib on young leaves at the apex of the mature plants, which can extend laterally to the leaf lamina. The yellowing of the midrib may turn pink or have a reddish tinge in some sugarcane varieties due to sucrose accumulation. Older leaves show a red coloration of the midrib on the adaxial surface. Afterwards the leaf blade becomes bleached, proceeding from the tip toward the base of the leaf and tissue necrosis can eventually take place. The yellowing can spread into the leaf blade and mid-veins can turn pink in severely infected plants.

Sugarcane YLD is characterized by apparent yellowing of the leaf from the midrib that further leads to necrosis. Necrosis appears first on the older leaves. Midrib yellowing of sugarcane leaves is the most predominant symptom observed in infected plants in different countries. The intensity of the lamina discolouration vary depending on the variety or crop stage. Necrosis of the discoloured tissue is noticed when the disease severity increases. Bushy appearance of the leaves in the crown of the plants due to internode shortening in maturing plants are commonly observed in YLD affected plants in susceptible varieties (Viswanathan, 2012) [86]. The lower surface of the midrib turns from green to bright yellow or pink or reddish. Dwarfism of the terminal internodes may also be observed (Lehrer and Komor, 2008) [46]. In severe cases, diseased plants are stunted and can be pulled easily. The yellowing can spread into the leaf blade and mid-veins can turn pink in severely infected plants. Leaf tips become yellow, then necrotic and necrosis may spread down the blade.

The disease infection results in reduction in sucrose content in stalks and accumulation of sucrose in leaf midribs and therefore yield losses. Hundred percent disease incidence was noticed in commercial fields planted with susceptible cultivars in different countries (Viswanathan, 2002, Comstock *et al*. 1998, Comstock *et al*. 2002 and Rassaby *et al*. 2004) [84, 15, 18, 62]. Non-symptomatic stage seems to be the most common epidemiological status for this viral disease. Schenck and Lehrer (2000) [68] reported that all the plants of susceptible varieties in Hawaii were infected with ScYLV, but disease symptoms appeared only occasionally. YL symptoms in all varieties grown in Venezuela before or during the first ratoon are rarely observed and they are evident after the second ratoon (Izaguirre-Mayoral *et al*. 2002) [42].

The visual observation of the symptoms for assessing the disease spread both vertically and horizontally was assessed using the 0-5 scale. Chinnaraja and Viswanathan (2015) [14] developed a rating scale 0-5 based on varying disease symptoms under field studies to find out the sources of resistance against YLD.

**Table 1:** Yellow leaf disease (YLD) severity grades

| Disease Grade | Description |
|---|---|
| 0 | No symptom of the disease |
| 1 | Mild yellowing of midrib in one or two leaves, no sign of typical bunching of leaves caused by YLD |
| 2 | Prominent yellowing of midrib on all the leaves in the crown. No bunching of leaves |
| 3 | Progress of midrib yellowing to laminar region in the whorl, yellowing on the upper leaf surface and bunching of leaves |
| 4 | Drying of laminar region from leaf tip downwards along the midrib, typical bunching of leaves as a tuft |
| 5 | Stunted growth of the cane combined with drying of symptomatic leaves |

***Source*:** AICRP on Sugarcane-Annual Report (2014-15)


**Fig 1:** Symptoms of YLD at different severity grades (Adopted from AICRP on Sugarcane Annual Report:2014-15)

**7. Studies on variability in the pathogen**

ScYLV has a positive-sense, single-stranded genomic. Its RNA genome contains six major open reading frames (ORFs) that are expressed by a variety of mechanisms (Mayo and Ziegler-Graff, 1996) [51]. The three 50-proximal ORFs are translated directly from the genomic RNA and include ORF1, encoding the 72.5 kDa viral protease and ORF2, which is translated via a ribosomal frameshift within ORF1 to yield the 120.6 kDa viral replicase. ORF2 shows the most similarity to the RNA-dependent RNA polymerase (RdRp) genes of the *Polerovirus* (Smith *et al*. 2000) [74, 76]. ScYLV has been detected by both serological (Scagliusi and Lockhart, 2000) [65] and molecular methods (Irey *et al*., 1997 and Comstock *et al*., 1998) [39, 15]. Molecular methods are more sensitive than serological ones, their use on a large scale for routine diagnosis is more expensive and the use of polyclonal antisera has contributed greatly to the detection of the *luteovirus* by direct ELISA and TBIA (Schenck *et al*., 1997; Comstock *et al*., 1998 and Moutia and Saumtally, 2001) [67, 15, 53].

Schenk *et al*. (1997) [67] developed tissue blot immunoassay (TBIA) technique using polyclonal antisera to detect ScYLV. Moutia and Saumtally (1999) [52] reported suitability of double antibody sandwich-enzyme linked immunoassay (DASELISA), immune specific electron microscopy (ISEM) and TBIA for the detection of the virus from the suspected sugarcane clones. They also found the presence of the virus in many of the asymptomatic plants through these techniques.

ScYLV is a *Polerovirus* belonging to the family *Luteoviridae* having monopartite, non-enveloped, isometric particles of 24-29 nm diameter. The virus consists of single-stranded positive sense linear RNA genome (5900 nucleotides), icosahedral symmetry made of 180 coat protein units, with six open reading frames (ORFs 0, 1, 2, 3, 4, and 5) (Rott *et al*. 2008) [64]. So far, there are 9 ScYLV genotypes known to occur in the world with great genetic diversity within species (Abu Ahmad *et al*. 2006) [2]. Molecular techniques like polymerase chain reaction (PCR), reverse transcriptase (RT)-PCR and nested PCR assays are most sensitive than the serological techniques especially to detect sugarcane viruses at low concentrations.

Molecular characterization of virus associated with YLS in India through standardization of RT-PCR technique with new set of specific primers to detect the virus in the suspected samples was also established (Viswanathan *et al*. 2008) [81]. Duplex and Multiplex-RT PCR were developed for the detection of ScMV, ScSMV and ScYLV, three of the major RNA viruses widely prevailing in the sugarcane growing regions in India.

DAS-ELISA has also been successfully used to detect the pathogen in infected plant material (Scagliusi and Lockhart, 2000 [65]; Viswanathan, 2002 [84], Viswanathan, 2004 and Viswanathan and Balamuralikrishnan, 2004) [83]. Moutia and Saumtally (2001) [53] standardized diagnosis of ScYLV by ELISA in infected juice collected from sugarcane stalk tissues. They established that ScYLV is present in all the stalks of infected stools. Korimbocus *et al*. (2002) [43] developed TBIA to detect ScYLV using the serum. TBIA has been the most widely used technique to detect the virus in different countries (Comstock *et al*., 1998; Schenck *et al*., 1997 and Victoria *et al*., 2005) [15, 67, 80]. RT-PCR was developed subsequently to detect the virus in sugarcane. Aljanabi *et al*. (2001) [3] reported that ELISA is less sensitive than RT-PCR for detection of ScYLV. Goncalves *et al*. (2002) [34] developed an AmpliDet RNA system for the detection of ScYLV in sugarcane and its aphid vector *Melanaphis sacchari* and compared its sensitivity with that of DAS-ELISA, RT-PCR and NASBA combined with Northern blotting analysis. Now this technique is being routinely used to diagnose the presence of a virus in sugarcane with primers specific to the virus. More recently, real-time fluorescent (TaqMan) RTPCR assays (Korimbocus *et al*., 2002) [43] and multiplex PCR assay (Xiea *et al*., 2009) [97] are also developed.

In India, identification of ScYLV in both symptomatic and asymptomatic plants have been performed by RT-PCR using the virus specific primers (Viswanathan *et al*., 2008, 2009 & 2010) [81, 90, 89]. Higher sensitivity and specificity of real-time quantitative PCR (RT-qPCR), confirmed the association of ScYLV and its quantification in asymptomatic sugarcane plants.

ScYLV has high genetic diversity within the species and presently ten genotypes are known to occur based on the complete genome sequence information. ScYLV is present in almost all the states of India where sugarcane is grown. Virion comprises of 180 coat protein units and are 24-29 nm in diameter. Phylogenetic analysis has confirmed the worldwide distribution of ScYLV genotypes (BRA, CHN1, CHN3, CUB, HAW, IND, PER, and REU). Evidence of recombination has been found in the ScYLV genome, which contains potential recombination signals in ORF1/2 and ORF5. This shows that recombination plays an important role in the evolution of ScYLV.

**8. Alternate hosts of scylv**

Sugarcane had been considered the only natural host of YLV for more than two decades (Schenck and Lehrer, 2000, Comstock *et al*. 2001, Lehrer *et al*. 2001 and Lockhart and Cronje, 2000) [68, 19, 43]. ScYLV has a limited natural host range and mainly infect sugarcane (*Sachharum* hybrid), grain sorghum (*Sorghum bicolor*), and Columbus grass (*Sorghum almum*). Natural occurrence of ScYLV was recorded on grain sorghum (*Sorghum bicolor*) cv. Top76-6 by Elsayed *et al*. (2014) [24] based on the NCBI GenBank accession numbers (KT960997, KT960996, and KT960995). Similarly, from the United States the natural occurrence of ScYLV on *Sorghum bicolor* and Columbus grass (*Sorghum almum*) was identified (Espinoza-Delgado *et al*., 2016 and Wei *et al*., 2016) [6, 95].

In 2014, the virus was reported in barley (*Hordeum vulgare*) in Tunisia [Bouallegue *et al*. 2014]. More recently, ScYLV was found in both *Sorghum almum* and *Sorghum bicolor* in Florida [Espinoza Delgado *et al*. 2016 and Wei *et al*. 2016] [6, 95]. The latter, commonly known as sorghum, is a grass species related to sugarcane and maize (*Zea mays*) which is not commercially grown in Florida. On the other hand, *Sorghum almum*, also known as Columbus grass, is a robust, short-lived perennial grass that can be found worldwide between 25˚N and 30˚S latitudes and starting at sea level up to a 700 m altitude (Heuze *et al*. 2015) [38]. Columbus grass is considered one of the most valuable summer forage and fodder crops in semi-arid and sub-humid areas but also a noxious weed in several states of the USA and Australia (Cook *et al*. 2005 and FAO, 2018) [20, 29].

**9. Transmission of scylv through vectors**

The virus has been known to be transmitted by the sugarcane aphid *Melanaphis sacchari*, the corn leaf aphid *Rhopalosiphum maidis* and the rice root aphid *Rhopalosiphum rufiabdominalis*. The sugarcane aphid acquires the virus

during feeding on an infected plant. The aphid retains the virus for life and can transmit ScYLV during feeding to healthy plants within the same field or in other fields. ScYLV was successfully inoculated using viruliferous aphids on barley, sorghum, wheat, maize, sweet corn, and oats. (Rassaby *et al*. 2004) [62].

ScYLV can be transmitted from infected to healthy sugarcane by the common aphids but not by mechanical transmission (Scagliusi and Lockhart, 2000) [65]. A high percentage of transmission of the virus to sugarcane has been observed with *Melanaphis sacchari* [Scagliusi and Lockhart, 2000) [65]. In Brazil, the yellow sugarcane aphid (*Sipha flava*) also transmitted ScYLV (Lopes *et al*. 1997) [49]. In China, the other aphid species, *Ceratovacuna lanigera* was reported.

Long range ScYLV transmission in sugarcane was achieved through infected seed canes and secondarily by aphids in a persistent manner (Rassaby *et al*. 2004) [62]. The virus is mainly transmitted through infected planting materials (Viswanathan *et al*., 2006) [87] and secondary spread is achieved through aphid vectors (Lehrer *et al*., 2007; Rassaby *et al*., 2004 and Scagliusi and Lockhart, 2000) [62, 65, 68].

Aphids responsible for the secondary spread of YL are expected to have increased survival with milder winter temperatures and summer temperatures. Virus transmission can be affected by several factors such as plant age, the number of aphids used for transmission, the feeding time and the inoculation access period. The virus is not transmitted mechanically, therefore, its transmission by *Melanaphis sacchari* has been studied in different countries.

ScYLV is a member of the *Luteoviridae* family and cannot be transmitted mechanically. This virus is spread by infected stalk cuttings and by at least four aphid species in a persistent, circulative, and non-propagative manner: *Melanaphis sacchari*, *Ceratovacuna lanigera*, *Rhopalosiphum maidis* and *R. rufiabdominalis* (Scagliusi and Lockhart, 2000, Schenck and Lehrer, 2000 and Zhou *et al*. 2006) [65, 68, 100]. Among these, *Melanaphis sacchari*, commonly known as the sugarcane aphid, is the most efficient vector of ScYLV worldwide and the most widespread in the Western hemisphere [Rott *et al*. 2008] [64]. Despite the variability in transmission condition used, several studies have shown the ability and efficiency of *Melanaphis sacchari* to transmit ScYLV from infected to healthy sugarcane (Abu Ahmad *et al*. 2007, Scagliusi and Lockhart, 2000, Schenck and Lehrer, 2000, Chinnaraja and Viswanathan, 2015 and Lehrer *et al*. 2007) [1, 65, 68, 14]. The disease also could be successfully transmitted to barley, maize, Erianthus, rice, oats and wheat by *Melanaphis sacchari* (Scagliusi and Lockhart, 2000 and Schenck and Lehrer, 2000) [65, 68].

The host range of the sugarcane aphid *Melanaphis sacchari* (Zehntner) is restricted to members of the genera *Oryza*, *Panicum*, *Pennisetum*, *Saccharum*, and *Sorghum* [Denmark, 1988 and Singh *et al*. 2004] [23, 71].

## 10. Management of Yld

The new disease YLD causes serious damage to cane productivity. Propagation of sugarcane through vegetative cuttings favours spread of diseases through planting materials. Primary transmission of different diseases through seed canes poses serious threat to sugarcane growth and performance. All the popular varieties were infected with YLD. Disease severity varies from different varieties cultivated in different agro-climatic conditions worldwide.

Managing ScYLV is difficult due to its vector-borne nature and transmission through infected seed cane. Knowledge of ScYLV, its vector, its hosts other than sugarcane, and its causal agent in order to manage the disease are needed to confine ScYLV infection to a low level. Integrated management strategies including cultural, chemical, biological, and other conventional strategies including identification of sources of resistance and breeding for disease resistance and non-conventional approaches including pathogen derived resistance, RNA silencing, miRNA and CRISPR/Cas (Clustered Regularly Interspaced Palindromic Repeats) needs to be adopted.

- Continuous monitoring of the disease through remote sensing technique has to be adopted for the identification of YLD affected sugarcane fields (Palaniswami *et al*., 2014 and Viswanathan *et al*., 2017) [54, 88] as YLD is transmitted by the aphid vectors.
- Wide-row spacing and early planting can alleviate the impact of YLD (Palaniswami *et al*., 2014 and Viswanathan *et al*., 2017) [54, 88].
- Healthy seed cane production by three-tier system must be emphasized for enhanced sugarcane productivity in India (Singh and Singh, 2015) [72].
- Epidemic nature of the disease may also be attributed to the prevalence of large populations of the vector in the field. The regular stripping of mature leaves from sugarcane may help to reduce the aphid population from the plant. *Melanaphis sacchari* was found as the only sugarcane aphid species spreading ScYLV in India, development of cultivars resistant to the vector can be a good management tactic to reduce the spread and incidence of the virus and its aphid vector.
- Biological control of aphid vectors could possibly reduce the widespread occurrence and spread of YLD in sugarcane. It has been demonstrated that 45% reduction in aphids was achieved due to the practise of application of grey fungus *Verticillium lecanii* (Hall, 1987) [36]. Predators have been showed very efficient bio-control agent for *M. sacchari* infesting sugarcane including *Ollav nigrum* (Mulsant), *Allograpta exotica* (Wiedemann), *Coleomegilla maculate fuscilabris* (Mulsant), *Hippodamia convergens* (Guerin), *Diomus terminates* (Say), *Lysiphle bustestaceipes* (Cresson), *Micromus subanticus* (Walker) and *Chrysoperla externa* (Hagan) (Hall, 1987, 1988; White *et al*., 2001) [36, 37, 96].
- Application of chemical control (dimethoate, edosulfan, monocrotophos or chlorpyriphos) was found to be effective against *Melanaphis sacchari* (Balikai, 2004 and Viswanathan *et al*., 2017) [9, 88]. However, application of insecticide sprays to manage aphids is not feasible when crop in field is more than five to six months old, for which automatic aerial sprays are helpful.
- Thermotherapy, tissue culture, and chemotherapy can used for elimination of viruses from plants. However, thermotherapy and chemotherapy often fail to eliminate pathogens when used alone, but their combination with the meristem culture technique gives satisfactory results (Balamuralikrishnan *et al*. 2002; Ramgareeb *et al*. 2010 and Wang and Valkonen, 2008) [8, 58, 93]. Meristem tip, axillary bud, and callus culture may be used for elimination of ScYLV from commercial and noble sugarcane cultivars with variable rates of success (Chatenet *et al*. 2001; Fitch *et al*. 2001; Parmessur *et al*. 2002 and Ramgareeb *et al*. 2010) [12, 31, 55, 58]. The meristem culture technique is the most widely used

method for virus elimination in meristematic tissues of apical shoots. This technique takes advantage of the fact that many viruses fail to invade and replicate in the meristematic region (Faccioli and Marani, 1998) [28]. Chatenet *et al*. 2001 [12] reported that apical meristem culture was an efficient method for the elimination of ScYLV, with a 92% success rate.

- Identification and deployment of resistant varieties (Schenck and Lehrer, 2000) [68] and employment of a cultivation scheme in which virus-free cane plants, generated by meristem tip culture, are grown for seed piece production in fields remote from commercial sugarcane fields.
- Management of the disease through identification of disease resistance in germplasm and developing resistant varieties through conventional breeding but also using biotechnological methods. The transgenic approach to producing high-yielding sugarcane cultivars with resistance to ScYLV seems to be a valuable option for regions with high incidence of the virus (Zhu *et al*. 2010) [101]. Resistance has been explored in breeding programs and by a few genetic mapping studies (Costet *et al*. 2012; Debibakas *et al*. 2014; Islam *et al*. 2018; Yang *et al*. 2019 and You *et al*. 2019) [21, 22, 40, 98, 99].

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