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Compiled and Edited by

G.V. Nair
R. Viswanathan
P. Govindaraj
K. Mohanraj

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Emerging diseases of sugarcane and recent approaches in sugarcane disease management

R. Viswanathan
Head, Division of Crop Protection,
Sugarcane Breeding Institute, ICAR,
Coimbatore 641007

In the past 90 years, hundreds of improved varieties were identified and popularized for commercial cultivation in India. However, only a few varieties have stood in the field and benefited the farmers in a sustainable way. During the period several varieties have succumbed to red rot, smut and wilt. When the disease incidence increases at an alarming rate due to development of disease epidemics, cane yield declines drastically and the subcontinent witnessed several epidemics of red rot during the past and during each epidemic a popular variety was removed from cultivation (Viswanathan, 2010). Impact of these fungal diseases to sugarcane cultivation has been thoroughly established. Ratoon stunting (RSD) and grassy shoot (GSD) have been found to cause considerable yield losses in some regions. Among the viral diseases, mosaic is prevalent in almost all the states in the country. However, in the recent years emergence of yellow leaf disease (YLD), *pokkah boeng* and rust as a serious constraint is found in many states. Sudden emergence of these diseases to epidemic levels poses challenge to varietal planning and successful cropping in different regions in the country. The review summarizes the current disease scenario in sugarcane, emerging diseases and new approaches to manage the diseases.

Current sugarcane disease scenario in the country

Red rot, smut and wilt continue to be the major diseases affecting sugarcane in different states. Other diseases with notable presence and damage are *pokkah boeng*, yellow leaf disease and rust (Table 1). In the recent years we have witnessed break down of the cvs CoS 8436, CoSe 95422 and BO 138, the important commercial varieties to red rot in the subtropical region. Severe damage to crop stand is found in these varieties due to disease epidemics in the states of Haryana, Uttar Pradesh and Bihar. The varieties Co 6304, Co 86002, Co 91017, Co 92012, Co 94012, Co 97009, CoC 671, CoC 90063, CoC 92061, CoV 89101, CoV 94102, CoV 06356, 91V83, 89V44, S-16, CoSi 6, CoSi 95071 and PI 96-843 in the tropical region; Co 1148, CoJ 64, CoJ 85, CoLk 8102, CoPant 84212, CoS 767, CoS 8436, CoS 88230, CoSe 92423, CoSe 95422 etc in the subtropical region show moderate to severe infections of red rot. Combined infections of red rot and wilt in severe form was found in CoSe 95422, CoS 8436, BO 138, Co 1148 and CoLk 8102 in Bihar.

In Andhra Pradesh, widespread cultivation of CoA 92081 resulted in severe outbreak of smut. Also introduction of highly susceptible variety CoV 05356 (99V30) in different parts of the state resulted in severe epidemics of smut. During the last season, moderate to severe smut occurrences have been found in varieties such as CoA 92081, CoV 05356, CoV 06356, Co 6907, Co 86032, CoA 08323 and S-16 in the state. Similarly, severe smut is noticed on Co 86002, CoN 95132, Co 97009, Co 7527 and CoSi 95071 in Gujarat, on Co 97009, CoSi 6, PI 96-843, CoSi 95071 and Co 86032 in Tamil Nadu. The varieties Co 8011, Co 740, Co 86032, CoC 671 and Co 94012 showed the disease in parts of Karnataka and Maharashtra. Although smut is not serious in the subtropical region, CoS 96275, CoS 96269, CoSe 98231, BO 150, CoPant 84212, Co 89003 etc recorded mild infections.

Large-scale wilt infection combined with root borer infestation on CoC 671, Co 86032 and CoM 0265 was reported in Maharashtra. The varieties CoV 89101, Co 6907, Co 7219, Co 95020, Co 86032, Co 97009, CoC 671, Co 86032, Co 86002, Co 86249, CoSi 95071 and Co 8145 exhibited varying levels of wilt in Andhra Pradesh and Gujarat. In Gujarat, combined infections of red rot and wilt were recorded in varieties such as CoC 671, Co 6304, Co 86032 and CoSi 95071. From Bihar also such combined infections were reported on many varieties. In Uttar Pradesh also severe to moderate levels of wilt in CoS 98259, CoSe 92423, CoS 8432, CoS 88230, CoS 96275 and CoSe 95422 were recorded. In Punjab, severe wilt was noticed on Co 89003. In other states also moderate incidences of wilt was reported.

In the last season, occurrence of *pokkah boeng* on popular varieties like CoS 767, CoS 8432, CoS 8436, CoS 88230, CoSe 95422, CoS 97261 and CoS 98259 in Uttar Pradesh, Co 86032, CoC 671, Co 7527, Co 8014, Co 7219, Co 94012, Co 05002, CoM 08090, CoVSI 9805, CoM 0265 and VSI 434 in Maharashtra and Co 7805, CoA 99082, CoV 94102, 98V95 and 2000V59 in Andhra Pradesh was reported. In Haryana, moderate incidences of the disease were recorded in CoH 151, CoJ 85 and CoS 8436. In other states, trace to moderate levels of *pokkah boeng* was recorded. In Tamil Nadu the disease was recorded on the varieties Co 86027, Co 95020, Co 99004 and Co 0323 grown in isolated pockets. The predominant variety under cultivation, Co 86032 remained free from the disease.

Yellow leaf disease (YLD) has been found to occur in serious form in different parts of the country. However, such reports have come only from tropical region. The varieties CoV 92102, CoV 94102, CoV 06356, 83A30, CoA 92081, CoA 05323, CoC 92061, Co 740, Co 8011, Co 86032, Co 94012 etc recorded moderate to severe YLD in Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu.

Among the foliar diseases rust has been found to seriously affect sugarcane in Maharashtra on the popular varieties viz. CoM 0265, CoVSI 9805, Co 86032, Co 92005, CoC 671 and Co 94012. In Andhra Pradesh also rust infection to 50-80% foliage area was reported on CoV 06356, Co 6907, Co 7219, 97R129 and 85R106 during November-December in the last season. The author has witnessed severe outbreak of brown rust on CoVc 03165 in Mandya region during 2009. The rust pustules have completely covered the canopy and due to the extreme susceptibility, the variety could not be cultivated. An iron carpet-like appearance over the canopy of the foliage occurred in the fields. The other varieties like Co 94008, Co 94012, CoC 671, VSI 434 etc which were under multiplication also suffered due to rust in the season. In the same area the major varieties under cultivation such as Co 62175 and Co 86032 remained free from the disease, indicating a varietal tolerance.

Among other diseases, grassy shoot (GSD) remains to be the major disease seriously affecting almost all the commercial varieties in the country. Moderate levels of mild leaf scald were found on CoLk 8102, CoS 767, CoS 8436 and CoS 98231 in the subtropical region. Similarly moderate red stripe or top rot was found in Co 89003, CoS 8436, CoH 152, CoH 133, CoH 136, CoSe 92423, CoJ 64 and CoJ 85 during rainy season in North India. The varieties Co 740, Co 8011 and Co 94012 recorded moderate ratoon stunting in Karnataka. Eye spot was reported from CoM 0265 in Maharashtra. Similarly in the same state, the varieties Co 740, Co 7219, Co 94012, CoC 671 and VSI 434 exhibited severe mosaic.

Emerging diseases of sugarcane in India

Pokkah boeng

Although under normal situations it does not cause significant yield loss it has the potential to arrest the crop growth temporarily. As discussed earlier, the disease occurs in different states in very severe forms in high humidity areas. The disease manifests in two phases viz. *pokkah boeng* and top rot. The most common symptom is a malformed or twisted top, which gives this disease its name "*pokkah boeng*" from the Javanese language. Symptoms develop during rainy periods which coincide with grand growth period. Initially, young leaves are chlorotic at their base and patchy elsewhere on the blade. Chlorosis is most obvious on the lower surface of the leaf or in twisted laminar regions and affected leaves tends to be malformed. Development of further symptoms is dependent on the susceptibility of the variety and on environmental conditions. Young leaves may become infected in the spindle, resulting in pronounced wrinkling, twisting and shortening of the leaves. Sometimes the leaves are shortened to few inches without lamina having malformed midrib or growth of

the leaves ceases with few inches appears as a de-topped spindle. As the leaves mature, irregular reddish stripes and specks develop within the chlorotic areas. Infection in the spindle may reach the growing point and continue into the stalk.

Sometimes, the growing point is killed leading to development of top rot. Due to death of spindle, sprouting of the lateral buds occurs. Most of the *pokkah boeng*-infected canes generally recover from the symptoms but in top rot phase recovery is not seen. Upon recovery it is noticed that the normal whorl with remnants of twisted leaf portions of affected leaves are still twisting around the spindle. Symptom development begins early in the rainy season which normally coincides with rapid and vigorous growth of the canes. The three to seven months-old crops are most susceptible to the disease. Due to top rot, further growth of the cane is affected. In case of recovered canes, internodal elongation is severely restricted in several internodes depending on the disease severity. Twisted top with discolouration on the foliage and reduced internode elongation have caused alarm among the farming community and it becomes difficult to promote the affected varieties to large areas.

Recent studies of Viswanathan *et al.* (2011a) established that the pathogenic *Fusarium* associated with sugarcane wilt belongs to *F. sacchari* using different molecular markers and pathogenicity of *F. sacchari* isolates on sugarcane. During the current season, sudden outbreak of *pokkah boeng* across the country was noticed on several varieties. In some parts of the country due to the very severe disease occurrence, farmers were resorted to spray fungicides to contain the disease. The popular varieties like CoS 8436, CoH 119, Co 0239, Co 0118, CoJ 88, CoJ 85, CoSe 92423, Co 99004, CoVSI 9805, Co 0238, Co 95020, BO 141 etc were severely affected in different states. It was found that *Fusarium* sp associated with *pokkah boeng* also causes stalk infections and produces wilt. Further studies on characterizing *Fusarium* associated with *pokkah boeng* and wilt isolates using established molecular markers revealed that *F. sacchari* and *F. moniliforme* are associated with *pokkah boeng* in India (Viswanathan and Rao, 2011). In this regard, report from Malaysia by Siddique (2007) also suggests that majority of *pokkah boeng* associated *Fusarium* belonged to *F. sacchari*. Further, recent observations at Coimbatore and in factory locations by the author indicated that severe infections of *pokkah boeng* may lead to wilt in some sugarcane varieties. The variety Co 86027 exhibited severe *pokkah boeng* up to 50% in Tiruppur and Dindugal districts in Tamil Nadu during this season. Due to the impact, substantial reduction in elongation of 2-3 internodes was observed with occasional top rot induced dead hearts. However, the fields with severe water logging exhibited wilt and it was found that due to adverse field conditions aerial infecting *Fusarium* has become systemic in sugarcane probably causes wilt. *Fusarium* isolates from foliar tissues, stalk, root and soil were recovered and are being studied using molecular tools to characterize sugarcane

associated Fusaria. It is expected that further studies in this area would bring a new dimension on the Fusaria associated with *pokkah boeng* and wilt and epidemiology of wilt in sugarcane, especially on survival of *F. sacchari* and its possible manifestation as foliar as well as stalk disease.

Yellow leaf disease (YLD)

Yellow leaf disease (YLD) in sugarcane earlier described as yellow leaf syndrome (YLS) is characterized by a yellowing of the midrib and lamina, reported from almost all the sugarcane growing countries. YLS is the name given to a disease that appeared in Hamakua (Hawaii) on variety H65-7052 in 1989 (Schenck, 1997). However, genesis of YLD started most likely earlier because earlier reports of sugarcane leaf yellowing exist, such as yellow wilt in East Africa in the 1960s (Ricaud, 1968). The author reported the occurrence of the disease with detailed account of symptomatology in India (Viswanathan, 2001a, 2002, 2008). *Sugarcane yellow leaf virus* (SCYLV) was established as the causal agent of the disease in India (Viswanathan et al. 2008a) and other countries. The recent works carried out at SBI and researchers in other countries clearly established that the disease is responsible for varietal degeneration in sugarcane (Comstock and Miller, 2001; Lehrer et al., 2007, 2009, 2010; Rassaby et al., 2003; Viswanathan and Murali, 2012).

Although the disease was there in different parts of the country for more than 10 years, its prevalence are ignored probably due to leaf mid rib yellowing is thought to be a phenotypic character in leaves. Even in case of severe symptoms with extensive foliar drying during the maturity phases, the impact of the disease impact is ignored. In this case it is construed to crop ageing or to other environment stresses. The epidemic occurrence of the disease has taken a toll on many varieties without being noticed by the concerned people that the poor performance of the varieties is due to YLD (Viswanathan, 2011). In ratoon crop, the intensity of the disease will be much higher than in plant crop.

The disease incidence is found more in poorly maintained crops. It is observed that infestation with internode borer, flowering, drought conditions, *Striga* infestation, and infection with other pathogens such as ratoon stunting, grassy shoot etc favour early expression of the disease. The sugarcane varieties showing mild symptoms usually record normal cane growth. In severely infected clumps, cane thickness and stalk height are significantly affected and the internodes are shortened. This effect culminates in bunching of leaves at the top. Usually such infection results in drying of entire clumps. Combined infection of SCYLV and RSD bacterium in sugarcane causes severe stunting than their infection alone (Viswanathan, 2002; 2004).

Impact of YLD on sugarcane

Recently, detailed studies were conducted at SBI on the impact of YLD on sugarcane growth and yield under field conditions by comparing disease infected canes with asymptomatic canes in the diseased field and disease-free canes in the healthy field (Viswanathan et al., 2010). Reduction in cane weight of diseased canes was 37.23% as compared to asymptomatic plants in diseased field and it was 15.69% as compared to disease-free canes. Reduction in cane diameter in the diseased canes was 15.25 % as compared to asymptomatic canes and 14.09% as compared to the disease-free canes. Also for number of internodes, asymptomatic and diseased canes showed significant difference between them. Average juice yields of 429.6, 347.0 and 279.5 ml/kg were recorded in disease-free, asymptomatic and diseased canes, respectively at 12th month in the popular cv Co 86032. Juice quality analysis revealed that there is a comparative reduction in % brix, % sucrose and CCS% and significant reduction in purity of diseased field canes as compared to healthy field canes. Cane productivity in the sugar mill area also showed a steady decline and reached to the lowest of 77.5 t/ha from 95 t/ha in 10 years.

Further, impact of YLD on physiological parameters was studied in the field by comparing healthy and diseased plants of nine cultivars viz., Co 419, Co 775, Co 86032, Co 94008, CoC 671, CoC 85061, CoPant 84211, CoV 92101 and CoV 92102. About 14 growth/physiological parameters viz., height of the cane, number of internodes, number of leaves, internodes length, stem weight, sheath weight, leaf weight, dry weight of leaf, stem and sheath, photochemical efficiency, leaf chlorophyll, leaf area index, photosynthesis rate, stomatal conductance and transpiration rate were recorded during formative and grand growth stages. Results of the study showed that there is a marked reduction in plant height, number of internodes and internodal length in the infected canes during the grand growth than formative stage. YLD-infected sugarcane plants recorded lesser photosynthetic activity and reduced mobilization of photosynthates from the leaves to stalk, thereby reducing the sucrose accumulation in the affected stalks (Viswanathan et al. 2011).

The causative virus of YLD colonizes the phloem elements in sugarcane, due to that it impairs movement of photosynthates from the leaves to stalk. Probably virus concentration inside the affected cells decide the impairment of translocation of photosynthates, such impairment directly affects the source to sink movement of sugars. In normal tissues, all the photosynthates synthesized during the day time are translocated to the stalk, during the night. In YLD-affected plants such movement does not happen and when photosynthesis starts in the day, the left over photosynthates remain there in leaves, hence,

photosynthetic efficiency is reduced. The poor photosynthetic ability of the affected plant affects plant growth significantly.

The incidence of the disease in commercial fields can reach upto 100 per cent in susceptible cultivars in USA mainland and Reunion (Comstock et al., 2001; Rassaby et al., 2004). Grisham et al. (2001) in Louisiana found yield losses of 6%, 11% and 14% in the plant crop, first and second ratoon of cv LCP82-89 in Louisiana with reduced stalk number and tonnage and without affecting the quality components of Brix %, sucrose %, fibre % and purity %. In contrast, SCYLV had a positive impact on several leaf components like Brix %, sucrose % and purity % were higher in juice from virus-infected green leaf tissue compared to healthy leaf tissue. Their subsequent field experiments showed reduction in cane and sucrose yield in cultivars HoCP 96-540 and L 97-128 due to SCYLV infection, but in LCP 85-384 reduction of cane yield noticed without reduction in sucrose yield (Grisham et al., 2009).

Rassaby *et al.* (2003) conducted detailed studies on the impact of SCYLV infection on sugarcane growth and yield in Reunion. Comparison of healthy and virus-infected canes from three varieties showed difference for 7 out of the 10 measured parameters in the cv R577. A greater impact of SCYLV on yield of cultivar R577 was found in the first ratoon crop compared to the plant crop: 46% reduction of stalk weight (vs. 28% in the plant crop), 13% reduction of stalk diameter (vs. 7% in the plant crop), and significant reduction in tonnage (37%). However, they found that the number of stalks per stool was not affected in either crop. The stalk height reduction was lower in the first ratoon crop when expressed as a percentage (18% vs 28% in the plant crop). Although no impact of SCYLV was detected in other two varieties in the plant crop, several yield components in them in the first ratoon crop were significantly lower in virus-infected than in virus-free plants. They concluded that the impact of SCYLV and tolerance of sugarcane to the virus vary according to sugarcane cultivar. In Brazil, the cultivar SP71-6163 extensively grown in the state of São Paulo suffered due to the disease and yield losses reached as high as 50 percent in the mid-1990s (Vega et al. 1997; Matsuoka and Meneghin, 1999; Lockhart and Cronje, 2000).

In Florida, yield of cane and sucrose yields were reduced by 11% in SCYLV-infected plots compared to virus-free plots when the results were compared for the five cultivars tested (Comstock and Miller, 2004). Lehrer et al. (2007) from Hawaii found fresh weights of comparable internodes of the infected plants are only 20–65% the weight of healthy plants, whereas the sugar concentration per gram fresh weight of the internodes is higher than in the healthy plant. Later field trial comparing plants of cv. H65-7052 of low and high SCYLV-titre in Hawaii showed that the field plots with plants of high virus titre

developed YLD symptoms and yielded only 54-60% of cane and sugar tonnage compared to plots with plants of low virus titre (Zhu et al., 2010). In healthy sugarcane plants, root dry weight was positively correlated with fresh weight, stalk number, Brix and sucrose content. In contrast, in SCYLV infected plants, root dry weight was negatively correlated with fresh weight and stalk number. These results suggest that in healthy plants, a well-formed root system is crucial for plant development as it provides aboveground plant parts with sufficient water and nutrients for proper growth (Vasconcelos *et al.*, 2007).

Other viral diseases

Over the years, importance of mosaic has not been felt in the country, although it has been reported several decades ago. Despite, mosaic is not a major problem in some countries; it has caused substantial yield losses in other countries by severe outbreaks of the disease. Previously there is a general opinion among sugarcane workers that mosaic does not cause any appreciable damage to the crop (Chona and Rafay, 1950). However, the economic losses depend on varietal susceptibility, virus strain, its interaction with other diseases, vector population, and environmental conditions. The yield loss due to mosaic does more pronounced as the virus/viral strains persists in infected cane generation after generation which leads to decline in cane yield and sucrose content (Koike and Gillaspie, 1989) ultimately the affected cultivars are removed from commercial cultivation. Studies conducted at SBI proved that two viruses viz. *Sugarcane mosaic virus* (SCMV) and *Sugarcane streak mosaic virus* (SCSMV) are associated with the disease (Viswanathan et al. 2007)

The author has observed severe expression of the disease in the popular varieties like Co 740, Co 7219, CoC 671, CoC 92061, CoJ 64, CoS 767 etc in different regions. Whatever the yield obtained in the field is presumed to be the achievable one under the specific situation ignoring the systemic nature of the disease and its possible impact on photosynthetic activity and cane growth. Earlier, Agnihotri (1996) reported that SCMV causes an appreciable damage in susceptible varieties and even 10-15 per cent yield loss due to this disease is highly significant because of extensive cultivation of the crop. Detailed studies on the impact of SCMV on cane growth and yield of two popular sugarcane varieties Co 740 and CoC 671 with virus free and virus-infected seed cane materials was taken up at SBI. The results revealed a significant reduction in sett germination and tiller production in both the varieties. Similarly a significant reduction in number of millable canes due to virus infection was found in both the varieties at the time of harvest. Virus infection significantly reduced the net CO_2 assimilation rate during the grand growth period. At harvest, cane stalks from virus-infected plots recorded a significant reduction in cane diameter, cane weight and number of internodes (Viswanathan and

Balamuralikrishnan 2005). From subtropical region also, such loss caused by mosaic was reported by many workers. Studies of Singh *et al.* (2003) from subtropical region assessed cane yield and CCS reduction in cvs CoLk 8102, CoPant 90223 and CoS 767 due to mosaic and it revealed 11.6 per cent mean reductions in cane yield and 11.71 and 9.84 per cent reductions in CCS in plant and ratoon crops, respectively. The disease affects almost all the varieties in the country. Since the incidence of sugarcane mosaic is almost 100% in India and considering the vast area under sugarcane cultivation, impact caused by it needs immediate attention.

Leaf freckle caused by Sugarcane bacilliform virus is reported long back in India (Viswanathan *et al.*, 1996) its distribution among the cultivated varieties is not established clearly. Recent studies conducted at SBI revealed that the disease widely prevalent in sugarcane fields and it causes severe symptoms on many varieties (Viswanathan, unpublished). In sugarcane germplasm, some of the virus infected genotypes exhibited poor growth (Viswanathan and Premachandran, 1998). However its impact on cane growth and yield has not been established in commercial varieties.

[redacted] degeneration

Research and development personnel have experienced this phenomenon over the years. Mostly fungal diseases like red rot, smut or wilt cause such sudden failure of varieties in sugarcane. However, another kind of loss caused to sugarcane productivity by the pathogens is least understood. Here slow build up of many non-fungal diseases in sugarcane causes decline in varietal performance and results in varietal deterioration. Viral pathogens and ratoon stunting bacterium systemically infect sugarcane over the years, which directly results in reduced cane and sugar yield. Although these viral/ bacterial pathogens cause limited symptoms in the field, continuous vegetative propagation results in enhanced pathogen titre that would increase the pathogenic potential to cause severe symptoms. Combined infections of two or more viral/bacterial pathogens accelerates the damage to the crop and this is due to infection of one pathogen making the plant more susceptible to another. In this way, a variety degenerates faster and its potential comes down over the years (Viswanathan and Padmanaban, 2008).

The RSD pathogen colonies system vessels which conducts water and minerals from root to leaves when bacterial colonization increases inside the vessels, the sap movement is restricted. Such impairment in sap improvement directly affects various metabolic processes, photosynthesis and transpiration in the plant. Although the pathogen does not affect these processes directly, its effect on water/nutrient movement to various tissues indirectly cause moderate

to severe impairment to plant growth and metabolism when sugarcane is infected either by SCYLV or bacterium, severe impact on cane growth and yield is expected. In many situations, author has found combined infections of both YLD and RSD in many sugarcane varieties. Such combined infections cause comparatively more severe impact on plant growth and development. When functions of both the conducting cells in the vascular system fail adverse impact on cane yield is expected. In addition, mosaic causing viruses also seriously impair plant growth and metabolism since these viruses systemically colonize all the tissues. This type of varietal degeneration due to combined infections of more pathogens was demonstrated in many varieties by comparing the growth in disease free and disease infected planting materials.

Earlier studies of Viswanathan (2001b) revealed that many varieties in Mandya region of Karnataka recorded high titre for *Liefsonia xyli* subsp *xyli* (Lxx). The results also revealed that those clones with severe RSD had severe symptoms of YLD. When SCYLV infection was combined with Lxx, drastic growth retardation was observed in many of the varieties. Subsequently, Viswanathan (2004) also observed that canes severely infected with RSD in varieties such as CoS 767 at Coimbatore or Co 419 in Karnataka state showed YLD infection to the tune of 100% in many fields. In such situation sugarcane growth was drastically reduced. Recent observation of Viswanathan (Unpublished) in Western Uttar Pradesh revealed that the predominant cv CoS 767 suffered due to YLD and RSD. The elite cultivar has become degenerated in several tracts and it needs an immediate attention. Agnihotri (1990) observed that a synergy between SCMV and RSD also exists and greater losses are incurred when sugarcane is infected with both pathogens simultaneously than when infected by either pathogen seperately. Since occurrence of YLD was not known that time it may be difficult to relate its association with varietal degeneration recorded before 1990s.

Decline in varietal performance over the years in the popular varieties is mainly due to accumulated pathogens inside the stalk affecting cane growth and photosynthetic efficiency, which directly results in reduced cane yield and sugar yield. Although these viral/ bacterial pathogens cause limited symptoms in the field, continuous vegetative propagation results in enhanced pathogen load that would increase the pathogenic potential to cause disease. Combined infection of two or more viral/bacterial pathogens accelerates the damage to the crop in the field and this is due to infection of one pathogen makes the plant more susceptible to another. In this way, a variety degenerates faster and its potential comes down over the years.

Recent approaches in sugarcane disease management

Stress factors and climate change

Many of the diseases like wilt, smut, YLD, sett rot, RSD and mosaic in sugarcane are aggravated by various biotic and abiotic factors. Also neglected crop suffer more from different biotic and abiotic factors like different borers, sucking pests, drought or water logging etc. Biotic factors such as infestation of borer pests or *Striga* favour early expression of YLD. Similarly root borer infestation favours wilt outbreaks in different regions. Also it is well known that early drought before south west monsoon and water logging after the monsoon favour wilt in different regions in the country. To some extent RSD is also aggravated similarly. Water logging during germination phase or during maturity phase favours pineapple disease either in planted setts or standing canes, respectively. Viswanathan (unpublished) has found "drought islands" in the drip irrigated fields due to improper laying or clogging of laterals in many places. This situation favoured early expression of YLD and severe symptoms of mosaic and ultimately poor yield inspite of additional expenditure. Severity of *pokkah boeng* is aggravated by top borer infestation in the subtropical region. Here again careful management of top borer has reduced incidences of *pokkah boeng*. These instances reflect the influence of different stresses; hence adequate care should be taken to minimize such predisposing stress factors in the crop to reduce the impact caused by severe disease infection.

Recently, Grisham et al. (2008) reported the usefulness of tools applied in precision agriculture to sugarcane pathology in USA. They found influence of environmental conditions and cultural practices on the incidence of brown rust and the infection was positively correlated with soil properties, particularly the levels of phosphorus and sulphur. It was deduced that excess fertilizer applications could bring about a higher rust incidence and thereby negatively affecting sucrose and cane yields. Similar studies are required under Indian conditions to assess the impact of various environmental factors on various stalk, foliar and soil borne pathogens in sugarcane. During the last few years, impact of climate change is being felt on crop growth and yield. How, climate change impacts on disease occurrence and epidemics in sugarcane have not been studied yet. Since sugarcane is being grown continuously throughout the year, it is getting exposed to all the vagaries of climate in all the growth stages. Such alterations may also favour the pathogens in gaining virulence and development of disease epidemics.

Disease surveillance

Taking preventive measures immediately on noticing the disease occurrence is the best way of avoiding any major outbreaks of the diseases. When due attention is not paid during the first infection stage it would lead to its eventual spread and thereafter attaining epidemic proportion. In general, either the field staff could not identify the disease correctly or ignored the likely build up of disease in later stages of the crop or in the ensuing ratoon. After planting the setts and proper regulations of irrigation water, the field will have to be kept under periodical disease surveillance. Regular monitoring and detection of all major diseases in the nursery and commercial plots, will keep them free from all major diseases. Also identifying and characterizing the pathogen populations regularly is also important to assess the pathogen variability in the region. Use of molecular or serological techniques would help in assessing the suspected pathogen in sugarcane.

Remote sensing using a fibre optic spectrometer was utilized to determine leaf infection by SCMV or SrMV. Analysis of mild and severe SCMV leaf reflectance measurements were correctly classified in 75 and 68% of the cases, respectively. Leaves infected by SCYLV were correctly identified in 77% of the time (Grisham et al., 2008). Recently at SBI, Coimbatore efforts were made to standardize use of remote sensing techniques to identify YL infection in the field. The results revealed a clear cut spectral differences between YL-infected and healthy fields (Palaniswami *et al.*, 2011). Further studies are required to optimize the same technique to identify other diseases, other biotic and abiotic constraints affecting sugarcane in the field. A comprehensive strategy to detect various stress factors will bring down the application cost and overall crop health status will be known to the researchers/industry.

YLD management

Disease free planting material is the prerequisite for the better crop establishment that will delay the disease development and spread. Since, sugarcane is propagated through vegetative cuttings that carry the virus to the field, supply of disease-free setts forms the basis of disease management in sugarcane. In certain countries, it was found that spread of the viral infection to neighbouring plants in the plantation fields via aphids was relatively slow and in the range of a few metres per year. No indication of long-distance transfer could be seen. This indicates that it may be possible to produce and use virus-free seed cane for planting of high-yielding but YLD-susceptible cultivars. However, SCYLV-infection proceeds at a rate of 20–80 per cent in Florida within 18 months (Comstock and Miller, 2004). Studies in this area of work have to be taken under Indian conditions.

Virus elimination through tissue culture

In many situations virus infection does not always lead to death of the plants. Although they do not show visible symptoms the presence of viruses in the plants can reduce the yield and quality of crops. It is well known that the distribution of viruses in plants is uneven. In plant pathology, tissue culture is being used for the elimination of plant pathogens in planting materials. Meristem and shoot tip culture are used to eliminate virus from infected germplasm. It has long been observed that the rapidly growing meristems of plants are usually free of viruses, or at least have much lower concentration of viruses than non-meristematic cells. This situation has been exploited for the production of virus-free plants by meristem culture. This approach has immensely helped in crop production by supplying virus-free tissue culture (meristem) plants in vegetatively propagated crops like banana, potato, sugarcane, cardamom, vanilla, ornamental crops etc. By this approach, it has been possible to eliminate SCYLV from many sugarcane commercial varieties worldwide. This technique takes advantage of the fact that some viruses are unable to colonise this region because of inhibition of replication and restriction of their movement. Two factors could impede with the replication of SCYLV at the meristem tip; a high concentration of auxin and depletion of nutrients through rapid cell division and secondly the inability of the virus to reside in the meristem as a result of:

a) localisation of the virus in the phloem which is not differentiated yet at the meristem tip,

b) inability of the virus to move vertically across the plant through the plasmodesmata to the meristem tip, and

c) inability of the virus to keep up with the pace of rapidly dividing cells at the growing point.

In Mauritius, Parmessur et al. (2002) eliminated SCYLV by tissue culture from infected sugarcane plants and the tissue culture derived regenerated plants remained free from the respective pathogens over a period of one year in the glasshouse. Previously, Chatenet et al. (2001) from CIRAD, France achieved virus elimination of 92 %, however they got only 64 % disease free plantlets. Hence stringent seed indexing has to be followed while screening of the regenerated plantlets. The potential for eradicating pathogens via rapid regeneration of plants directly from leaf roll discs was explored in South Africa. The technique, NovaCane®, has been used successfully to remove SCYLV (Snyman et al., 2006). In addition, this process enabled elimination of bacterial pathogens from diseased sugarcane plants while simultaneously enabling large-scale micro propagation.

Ramgareeb et al. (2010) used apical meristem culture for simultaneous virus elimination and shoot proliferation in sugarcane. Virus-free plants were propagated from SCMV and SCYLV-infected material of the South African commercial cultivar, NCo376. A combination of thermotherapy by hot water treatment of nodes and subsequent germination of vegetative buds at 40°C and optimal meristem size were key factors for the production of virus-free plants. Only meristems of 2 mm in length or of a smaller size (but <0.5 mm) resulted in virus-free sugarcane. Shoot induction and proliferation via direct organogenesis were achieved on MS medium supplemented with 0.1mg 6-benzyladenine and 0.015mg 6-furfurylaminopurine per litre. This seems to be a rapid proliferation method to multiply virus-free shoots from infected sugarcane plants and approximately 1,300 shoots were propagated from a single 2 mm meristem in 11 weeks. They have reported that the plants remained virus-free when tested 12 months later.

As disease eradication through meristem culture will not be 100% effective, it is suggested that mother plants require conventional screening for the presence of known pathogens prior to micropropagation. This reduces the rejection of thousands of seedlings with virus infection at later stages. Studies conducted at SBI, Coimbatore revealed that meristem culture combined with viricide Ribavirin has effectively eliminated the virus (Neelamathi, unpublished). The tissue culture seedlings derived through meristem culture performed well under field conditions due to freedom of the virus. Thus tissue culture combined with molecular diagnosis has become a proven technology to eliminate the virus and manage the disease. Studies of Viswanathan et al. (2011) revealed that disease-free crops of cv Co 86032 raised through virus-eliminated seed material record 6.8 to 14.16 % increase in cane yield as compared to the fields with diseased infected fields. Since the disease occurs in endemic level in many states there is an urgent need to replace the virus infected seed material with healthy seed canes to sustain cane yield.

Ever since YLD became a serious constraint to sugarcane production in different countries efforts were made to manage the disease through different strategies. Among the different approaches going for meristem culture technique was found to be more effective in the elimination of the causative virus from the systemically infected plants. Diagnosis of the targeted viruses is important in the meristem derived-plantlets to validate the process for virus elimination and to supply virus-free mother plants or planting materials.

YLD resistance in sugarcane

Sugarcane response to infection by SCYLV and the disease varies according to the variety, and numerous varieties can be infected by the pathogen

without exhibiting disease symptoms. Researchers have found that all clones in the varietal development programme become infected by the end of the 10-year programme. In the world collection of sugarcane and related grasses in Florida, incidence of SCYLV ranged from 7% in *S. spontaneum*, the most resistant group, to 76% in *S. officinarum*, the most susceptible group (Comstock *et al.*, 2001). Differences in virus infection rates between different species of *Saccharum* were also reported in Hawaii. Resistance to sugarcane infection by SCYLV and to YLD therefore appears the most promising method to control the disease. In Colombia, virus infection varied between 0% and 100% and a cross between a susceptible female parent and a resistant male parent resulted in mostly resistant progenies (Victoria *et al.*, 2005). Similarly studies are in progress in Hawaii, Louisiana, Brazil and other countries to develop YLD resistance in sugarcane, where artificial inoculation techniques through insect vectors was standardized.

Earlier studies of Viswanathan (2002) revealed that more than 30% of the varietal collections at Coimbatore are infected with YLD. Further studies carried out to identify disease resistance in sugarcane led to identifying varieties which are most resistance and susceptible to the disease. However there is a need to develop disease rating scale to quantify the disease resistance in sugarcane germplasm and progenies. At SBI, a new disease rating system was developed to identify disease resistance in sugarcane to the virus (Viswanathan et al., 2012). To estimate disease severity in disease infected plants a 0-5 severity grades were developed (Table 2). Based on the disease severity scores a disease rating system was developed to assess YLD resistance in sugarcane genotypes (Table 3).

In the past four seasons this disease rating system is being validated at SBI to screen sugarcane germplasm/parents for YLD resistance. Overall, 25.31 to 38.64% of the genotypes exhibited varying degrees of the disease susceptibility and the rest remained free from the disease. In this process the genotypes BO 91, Co 475, Co 527, Co 951, Co 975, Co 62175, Co 62197, Co 622, Co 678, Co 7202, Co 7318, Co 7527, Co 87025, Co 92002, Co 92020, Co 98014, Co 0120, CoC 92061, CoH 110, CoJaw 270, CoLk 8102, CoM 6806, CoM 0265, CoSnk 03754, Q 63, ISH 69, ISH 100, ISH 176, etc were found to be resistant to the disease. However, their true resistance to the virus has to be further confirmed by artificial inoculation experiments using viruliferous aphids.

Molecular diagnosis of sugarcane diseases

Many of the sugarcane diseases exhibit limited symptoms on the seed canes. Similarly to assess pathogen infection in tissue culture derived seedlings conventional techniques are not useful. Hence advanced laboratory techniques

have been developed to detect and diagnose sugarcane pathogens in sugarcane. Earlier, serological techniques were employed to detect sugarcane pathogens and recently more molecular diagnostics were developed. Detailed studies carried out at SBI, Coimbatore on disease diagnosis for the past two decades led to developing various protocols to detect viral, fungal, bacterial and phytoplasmal pathogens.

Early cause of mosaic was reported as *Sugarcane mosaic virus* (SCMV) and recent studies conducted at SBI established that *Sugarcane streak mosaic virus* (SCSMV) also associated with the disease. RT-PCR studies proved that the two viruses cause mosaic either alone or in combination (Viswanathan et al., 2007). Hema *et al.* (2001) standardized DAS-ELISA and DAC-ELISA for the diagnosis of SCSMV in leaf extracts, sugarcane juice and partially purified virus. Since association of two viruses either alone or in combination in causing mosaic in sugarcane further studies were conducted to detect the associated viruses in a single reaction. To optimize simultaneous detection of these viruses, a new set of primers were designed from the coat protein region of the viruses to suit duplex reverse transcription polymerase chain reaction (D-RT-PCR) and the conditions were standardized to amplify the target viruses in this assay (Viswanathan et al., 2006b). Further, the D-RT-PCR was found equally reliable to uniplex RT-PCR performed with SCMV and SCSMV primers in separate reactions.

Association of the virus with YLD was established through DAS-ELISA technique at SBI, Coimbatore (Viswanathan, 2002, 2004). Later, RT-PCR techniques were performed to detect the virus in the suspected varieties of sugarcane. In addition to the reported primers new set of specific primers (615F/615R) were developed to detect the virus by RT-PCR in the suspected samples and meristem derived seedlings (Viswanathan *et al.*, 2006, 2008a). The efficiency of the diagnostic primers *viz.*, SCYLV-615F and SCYLV-615R was further validated by Viswanathan et al. (2009) with a set of sugarcane samples collected before and after yellow leaf symptom expression. In pre-symptom expression, 34 of 44 samples gave a positive amplicon of ~615 bp in size in RT-PCR. The RT-PCR assay performed with the samples collected after symptom expression in the same set of varieties revealed that almost all the samples except one were found infected with SCYLV. Of the 43 positive samples, 10 were found apparently free from YLD symptoms. The RT-PCR assay established that 97.73% of the samples were found to be infected with SCYLV and the diagnostic primers efficiently detecting all the SCYLV population even in asymptomatic plants.

A multiplex-RT-PCR was developed for the detection of SCMV, SCSMV and SCYLV, three of the major RNA viruses widely prevailing in the sugarcane growing regions around the world. Four of the nine sugarcane samples including

an aphid colony were found infected with all the three targeted viruses, only two had infections of SCMV and SCSMV and the three viruses found separately in rest of the three samples. In this study, we have specifically amplified fragments of ~860 bp (SCMV), ~690 bp (SCSMV) and 615 bp (SCYLV) in M-RT-PCR (Viswanathan et al., 2010).

Presence of *Sugarcane bacilliform virus* (SCBV) associated with leaf freckle has been confirmed through serological techniques in germplasm clones (Viswanathan *et al.*, 1996, 1999). Later studies revealed that PCR was more sensitive than ELISA to detect SCBV in sugarcane (Balamuralikrishnan and Viswanathan, 2005). Recent studies conducted at SBI revealed that many of the cultivated varieties exhibit varying levels of the disease.

The fungus *Colletotrichum falcatum* is known to survive as dormant infection in cane tissues, making it difficult to diagnose under field conditions. Polyclonal antisera were raised against *C. falcatum* and ELISA techniques were standardized to detect the pathogen in cane tissues. Recent studies of Malathi (unpublished) revealed that specific primers designed to detect *C. falcatum* by PCR in cane tissue have precisely detected the fungal infection even before symptom development. Similarly DIG-labelled DNA probe was developed to detect the fungus in asymptomatic sugarcane tissues. Different techniques based on immunological, histological and histochemical methods were standardised for the detection of *Sporisorium scitamineum* (Syn *Ustilago scitaminea*), the smut pathogen (Nallathambi et al., 1998; Padmanaban, . These techniques have also been used in the screening of sugarcane varieties to smut reaction. Dormant infection of smut pathogen in the bud scales and apical meristem of sugarcane could be efficiently detected by these techniques.

Currently PCR technique is used to index seed cane for GSD phytoplasmas infection and RT-PCR technique is used to index sugarcane for SCMV, SCSMV and SCYLV infections and SBI offers diagnostic service to tissue culture production units. These diagnostics tests have become imperative to raise disease-free planting materials. Hence tissue culture production units in the country are utilizing the indexing service from Plant Pathology laboratory, which is an accredited test laboratory (ATL) under NCS-TCP programme of DBT, New Delhi for sugarcane virus testing in the country (http://dbtncstcp.nic.in/html/content/ATLs.html). The molecular tests are highly sensitive to detect very low virus titre in *in vitro* stock culture or in seedlings. These molecular techniques will be useful to raise disease free planting materials for sugarcane plantations. There is also possibility of maintaining the popular varieties for many years without degeneration to sustain higher productivity.

Chemical control

Chemical controls are possible for few of the diseases, particularly those caused by fungal pathogens. Sett rot pathogen survives in the soil. As a prophylactic measure, the setts are to be dipped in Carbendazim solution to protect the cut-ends from the pathogen. This practice is in vogue for several years and beyond that only limited studies have been conducted to establish efficacy of fungicides against major fungal diseases. Recent studies at SBI, Coimbatore revealed that sett treatment of Thiophanate Methyl fungicide alone or in combination with biocontrol bacterium *Pseudomonas* reduces debris borne infection of red rot pathogen (Malathi et al., 2002). If rust is severe five to six sprayings of Mancozeb (0.2%) between November and March is recommended to control. Similarly to control eye spot spraying of copper oxy chloride or Mancozeb (0.2%) once in 30 days during early period of disease is recommended. Whenever the disease is high, fungicidal application should be sprayed at fortnightly intervals.

Although there are limitations to extend disease management in standing crop through chemicals, the current disease scenario in case of red rot, smut and *pokkah boeng* warrant fungicide application to reduce the disease severity. To save future ratoon crops in case plant crop is infected with red rot or smut and to reduce disease intensity in plant crop, we have to explore fungicide delivery mechanisms for effective disease management in sugarcane. We have taken up detailed studies to enhance fungicide (Thiophanate methyl) uptake in the planting setts and this resulted in extended protection of sugarcane crop against red rot. Similarly it was found that delivery of Thiophanate methyl and liquid formulation of *Pseudomonas* through sub surface irrigation system effectively reduced red rot build up under endemic location. These new opportunities have created alternate strategies to manage red rot and other fungal diseases in sugarcane. This will also reduce the chaos during sudden outbreak of red rot in a new location or a variety by effectively protecting the crop.

Induced resistance

This is a recent approach exploited to manage many fungal diseases in different crops. Here, biotic agents like fluorescent pseudomonads or abiotic inducer molecules like salicylic acid and its analogues are being used to induce systemic resistance in crop plants against the target pathogen. The former approach is referred as induced systemic resistance (ISR) and the latter is described as systemic acquired resistance (SAR). Although the inducing agents are different, the net phenotypic effect on the crop plant is same. These approaches have been exploited in sugarcane against red rot and the results are

encouraging (Ramesh Sundar et al., 2006, 2009; Senthil et al., 2003, 2011; Viswanathan and Samiyappan, 2002, 2008). Recently efficient management of red rot using *Trichoderma* also reported (Singh et al., 2011). In addition to these agents, studies have been initiated to isolate and characterize an elicitor molecule capable of inducing systemic resistance (Nagarathnam, 2010). Further, this approach needs validation under endemic locations to identify best strain mixtures or combination of biocontrol agent and inducer to effective disease management. The newly identified biocontrol agents/molecules offer an alternate strategy to manage red rot.

Conclusion

The fungal diseases like red rot, smut and smut were responsible for the elimination of many elite commercial varieties in the past in different epidemics. Additionally many of the non-fungal diseases contribute to decline in their performance due to 'varietal degeneration'. Lack of awareness on seed cane health and ignoring quarantine regulations resulted in introduction of diseases, their epidemics and varietal degeneration in the country. The clones which can resist degeneration need to be identified at early stages of varietal selection to avert their rejection at ZVT stage. Sugarcane varieties vary in their potential against different diseases and any elite commercial variety may not possess tolerance against all the major diseases. Hence to sustain the productivity in such varieties alternate management strategies need to be developed. Recent outbreak of *pokkah boeng* and rust in different parts of the country could be due to climate change. Hence future research efforts should also focus on this area of science to address the issue of minor diseases becoming major diseases in sugarcane. Also Fusaria associated with sugarcane and their disease epidemiology needs to be studied in detail.

Although YLD has created a havoc to sugarcane cultivation in the country and we have evolved strategies to manage the disease through meristem culture combined with molecular diagnosis of the virus. Hence, need of the hour is to establish YLD-free nurseries in different sugar mills to reduce disease severity. Also YLD resistant parents have to be included the future breeding programme to manage the disease through disease resistance. Disease surveillance programmes in the country need further strengthening including use of remote sensing approach. This would lead to creation of disease maps for various diseases in sugarcane and this would facilitate developing possible forewarning systems and varietal deployment in a region in the future.

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Table 1 Current diseases scenario in sugarcane in India

States	Diseases noticed	Remarks
Assam	Pokkah boeng, mosaic	Mosaic 10-30% in major varieties and pokkah boeng to trace levels
Andhra Pradesh	Red rot, smut, wilt, rust, pokkah boeng, rust, ring spot, grassy shoot (GSD), yellow leaf (YLD), ring spot	10-40% red rot in CoV 89101, CoC 92061, CoV 06356, CoV 94102, S-16; severe smut in CoA 92081, CoV 05356, Co 6907, CoV 06356, Co 86032, CoA 08323, S-16; 10-30% wilt in CoV 89101, Co 6907, Co 7219, Co 95020; severe YLD in CoV 92102, CoV 94102, CoV 06356, 83A30, CoA 92081, CoA 05323, CoC 92061; 50-80% rust in CoV 06356, Co 6907, Co 7219, 97R129, 85R106 during November-December; pokkah boeng in Co 7805, CoA 99082, CoV 94102, 98V95, 2000V59; 10-20% GSD in ratoons of many varieties; 15-50% ring spot in many varieties during November-December.
Karnataka	Smut, YLD, GSD, mosaic, RSD, rust, eye spot, brown spot, other leaf spots	Smut, severe in Co 8011, moderate in Co 740, Co 86032, CoC 671, Co 94012; moderate to severe YLD in Co 740, Co 86032, Co 94012; moderate ratoon stunting in Co 740, Co 8011, Co 94012; grassy shoot in all the major varieties in trace to moderate level.
Tamil Nadu	Red rot, smut, yellow leaf (YLD), wilt, grassy shoot, pokkah boeng	Moderate infections of red rot in Co 92012, CoC 671, CoC 90063, Co 94012, CoSi 6, CoSi 95071, Co 91017, PI 96-843; moderate to severe incidences of smut in Co 97009, CoSi 6, PI 96-843, CoSi 95071, Co 86032; moderate

		incidences of wilt in Co 86032, Co 97009; severe infections of YLD in Co 86032, CoV 92102
Kerala	Red rot, leaf spot	Mild incidence
Gujarat	Red rot, wilt, smut, grassy shoot, pokkah boeng, rust, grassy shoot, pine apple	Moderate levels of red rot in CoC 671, Co 86002, Co 6304, CoSi 95071, Co 97009; severe smut in CoSi 95071, Co 97009, Co 86002, CoN 95132, Co 7527; wilt in CoC 671, Co 86032, Co 86002, Co 86249, CoSi 95071, Co 8145. Maximum red rot and wilt occurred in CoC 671.
Uttar Pradesh	Red rot, wilt, leaf scald, GSD, smut, pokkah boeng, top rot	Moderate to severe red rot in CoJ 64, CoS 8436, CoS 88230, CoS 767, CoLk 8102, CoPant 84212, Co 1148, CoSe 9243, CoSe 95422; traces of smut in CoS 96275, CoS 96269; wilt, very severe in CoSe 92423, CoS 98259, moderate in CoS 96275, CoSe 95422, CoS 8432, CoS 88230, Co 0238; severe GSD in CoS 8436, CoS 88230, CoSe 92423; moderate levels of pokkah boeng in CoS 8436, CoS 767, CoS 8432, CoS 88230, CoS 97261, CoS 98259; mild leaf scald in CoLk 8102, CoS 767, CoS 8436, CoS 98231; mild smut in CoS 98231; red stripe in CoSe 92423, CoJ 64
Bihar	Red rot, wilt, smut, red stripe, eye spot and top rot	Combined infections of red rot and wilt severe in CoSe 95422, CoS 8436, BO 138, Co 1148, CoLk 8102, CoSe 95422; traces to moderate smut in CoSe 98231, BO 150; trace to moderate levels of *pokkah boeng*

		in many varieties
Madhya Pradesh	Smut, wilt, red rot, mosaic, GSD, YLD	Moderate smut in Co 7219, Co 7318, Co 86032 and moderate YLD in many varieties.
Punjab	Red rot, wilt, smut, top rot	Moderate red rot in CoS 8436, Co 1148, CoJ 64, CoJ 85; mild to severe wilt on Co 89003; mild smut in Co Pant 84212, Co 89003; moderate GSD in CoJ 85, Co 0238, CoH 119; moderate red stripe and top rot in CoJ 854
Haryana	Red rot, wilt, smut, *pokkah boeng*, top rot	Severe incidence of red rot in CoS 8436, CoJ 64; *pokkah boeng* in CoH 151, CoJ 85, CoS 8436, moderate red stripe or top rot in CoS 8436, CoH 152, CoH 133, Co 89003, CoH 136 during rainy season,
Maharashtra	Rust, smut, wilt, *pokkah boeng*, mosaic, GSD, rust and leaf spots	Severe incidence of rust through out the state in CoM 0265, CoVSI 9805, Co 86032, Co 92005, CoC 671, Co 94012; *pokkah boeng* in CoVSI 9805, Co 05002, CoM 08090, Co 8014, Co 94012, VSI 434, CoC 671, Co 7527, Co 86032; eye spot in CoM 0265; moderate GSD throughout in CoM 0265, Co 86032, Co 740, Co 94012, VSI 434, Co 8014; mild wilt in association with root borer in CoC 671, Co 86032. CoM 0265; severe mosaic in Co 740, Co 7219, Co 94012, CoC 671, VSI 434; traces of red rot in CoC 671 in few pockets

(Anon. 2011)

Table 2 YLD severity grades in sugarcane

Disease grade	Description
0	No symptoms 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

Table 3 Disease severity scores to assess YLD resistance in sugarcane

Score	Disease reaction
0.0 - 1.0	Resistant
1.1 - 2.0	Moderately resistant
2.1 - 3.0	Moderately susceptible
3.1 - 4.0	Susceptible
4.1 - 5.0	Highly susceptible