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SUSTAINABLE SUGARCANE PRODUCTION IN INDIA *VIS A VIS* IMPACT OF SUGARCANE DISEASES

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Abstract

Sugarcane is a major commercial crop grown in tropical and subtropical regions of the country. During the last 100 years, the country has witnessed epidemics of various diseases like red rot, smut, wilt, rust, leaf scald and yellow leaf (YL). The loss caused by red rot is phenomenal, in which many elite varieties like Co 312, Co 419, Co 997, Co 1148, CoC 671 and CoJ 64 were removed from cultivation. During each epidemic, new virulent pathotypes of red rot emerged and posed challenge to sugarcane cultivation. Still, red rot remains to be major disease of sugarcane in the country and wilt and smut are the other two major diseases seriously affecting cane production. Severity of *pokkah boeng* and rust is also growing in many parts of the country. Sugarcane viruses causing mosaic and YL and ratoon stunting bacterium systemically infect sugarcane, over the years they reduce cane and sugar yield. The reduced performance of sugarcane varieties due to these non-fungal diseases is referred as 'varietal degeneration' and this phenomenon has been recorded in both tropical and subtropical regions in the country. Here combined infection 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 and under Indian situation this phenomenon has been ignored. The propagation material in sugarcane 'setts' plays vital role in the primary spread of diseases hence selection of healthy planting material plays a vital role in raising a healthy crop. Disease resistant varieties play a crucial role in managing many of the diseases in sugarcane and several varieties have been developed to manage the diseases in the past. In addition, different agronomical approaches and physical method like heat therapy are being effectively used to manage the diseases in sugarcane. Recently, multiplication of sugarcane through tissue culture is being advocated to produce disease-free planting materials. However there is a need to diagnose of pathogens in sugarcane setts or tissue culture seedlings for effective disease management practice. Meristem culture combined with molecular diagnosis has become a proven technology to eliminate *Sugarcane yellow leaf virus* causing YL in sugarcane and to manage the disease. Development of molecular diagnostics techniques has also facilitated precise identification and characterization of sugarcane viruses. Also this technique has the potential to detect more than one pathogen in one reaction and diagnosis is also amenable to automation. The review focuses on the prevailing disease situation, emerging new diseases, varietal degeneration in sugarcane, disease management using disease resistant varieties along with healthy seed nursery programmes.

Key words: Sugarcane diseases; varietal degeneration; meristem culture; virus elimination; molecular diagnosis

Disease scenario

Diseases are considered as constraint to sugarcane production all over the world, and no country is immune to the destructive influences of plant pathogens. In India, various diseases caused by fungi, bacteria, viruses and phytoplasmas have been reported to affect sugarcane production. In spite of all the efforts to replace through disease resistant varieties, sugarcane has become more and more prone to many diseases. Among the fungal diseases, red rot, smut, wilt and pineapple disease (sett rot) are the serious diseases affecting sugarcane production in India. The bacterial diseases, ratoon stunting (RSD) and leaf scald (LSD) are found to cause considerable yield loss in some regions in the country. Among the viral diseases, mosaic and recently recorded yellow leaf (YL) prevalent in almost all the states. Besides these, grassy shoot caused by phytoplasmas is also a potential disease, which can cause considerable damage to sugarcane production in the country. Besides foliar diseases such as rust, ring spot, eye spot, yellow spot, brown spot, brown stripe, etc may cause losses to sugarcane depending on the prevailing environmental conditions. Also 'pokkah boeng' considered as a minor disease has caused damage to cane growth on several varieties in the last few seasons.

In India, every year sugarcane diseases cause the loss of several millions of dollars. In the past, many high yielding, high sugar and popular cane cultivars like Co 312, Co 419, Co 453, Co 658, Co 997, Co 1148, Co 1158, Co 7805, CoC 671, CoC 92061, CoJ 64 etc were withdrawn from cultivation since they succumbed to new pathogenic variants of red rot (*Colletotrichum falcatum* Went) with more virulence. Similarly several other commercial varieties were discontinued due to their high susceptibility to smut [*Sporosorium scitamineum* (Syd.) M. Piepenbr., M. Stoll & Oberw. 2002, syn: *Ustilago scitaminea* Syd.] or wilt [*Fusarium sacchari* (E.J. Butler) W. Gams].

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Emerging new diseases

During 1999 when yellow leaf (YL) was first noticed in the country it was not thought to be a serious disease. However, in the past 10 years increased disease outbreaks were recorded in different states, which indicate that the disease has assumed a serious threat to sugarcane cultivation in the country. Although mild infections of the disease do not cause much crop loss, continuous use of seed from such fields leads to severe disease out breaks. In India, YL symptoms occurred in most of the sugarcane growing regions of the country and the disease intensity was recorded up to 100 per cent in certain susceptible varieties (Viswanathan 2002; 2008). Similarly, *pokkah boeng* has become a serious constraint in different parts of the country during the last season. Also severe occurrence of wilt was found in parts of Maharashtra and Tamil Nadu (Anon 2011). In many places, problems of wilt, RSD and GSD have been ignored, as there was no previous history of their severity. Due to introduction of new varieties or change in cultivation pattern, minor diseases become severe. Among the foliar diseases, rust has assumed serious constraint in different parts of Maharashtra and Karnataka.

Impact of the disease on cane growth and yield

The various types of diseases on sugarcane determine the quality, quality and stability of crop yield. This long duration cash crop due to its vegetative propagation, high sugar accumulation and practice of ratooning makes it easily susceptible to the diseases in the field. Besides this, wide spread practice of monoculture and favourable environmental conditions add to its susceptibility. This unfavourable environment in the host plant, invites large number of pathogens. The major fungal diseases like red rot, smut and wilt when occur in sporadic level juice quality is affected partially apart from loss in cane yield. However, during disease epidemics upto 100% yield losses are expected. The author has recorded many such severely affected crops due to all these three diseases. During the recent red rot epidemics on the popular cultivars, viz., CoC 671, CoC 92061, CoJ 64, CoS 8436, CoSi 96071, Co 6304, Co 7805, CoSe 95422 etc in different states, complete loss to the crop was recorded. Similarly ratoon crops of CoV 05356 and CoA 92081 suffered severely due to smut in parts of Andhra Pradesh. Such severe disease outbreaks cause destabilizing effect in sugarcane agriculture in the country. Both the farmers and sugar industry loose by way of loss in productivity and juice quality, respectively in the country. Impact of red rot to sugarcane has recently been reviewed by the author (Viswanathan 2010). Sudden outbreaks of these diseases force sugar industry to replace the susceptible variety with new varieties. Usually replacing a well adopted variety with another variety in a region is very difficult due to the grower's reluctance to new varieties. Also the industry has to invest more to popularize new varieties. In such a situation the research institutes are also put into extra pressure in identifying and releasing new varieties. Overall, the impact of these major fungal diseases results in i. elimination of well adopted varieties from the region, ii. increased pathogen virulence, iii. loss of ratoon crops to growers and reduced cane crushing in the sugar mills and iv. additional investment in seed multiplication for the sugar mills.

Varietal degeneration

The non-fungal pathogens like viruses causing YL and mosaic and ratoon stunting bacterium systemically infect sugarcane. Over the years, such systemic accumulation of these pathogens reduces cane and sugar yield. In contrast to fungal diseases, where very severe losses to crop yield are expected in the field, these non-fungal pathogens in sugarcane causes gradual decline in varietal performance. 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 infection 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 in the field after some years in the field. This phenomenon is referred to as 'varietal degeneration' in sugarcane (Viswanathan and Padmanaban 2008). The pathogens are not only reducing the yield but also cause the deterioration of the variety due to their accumulation in the stalk over long period of time. Degeneration of popular cv Co 419 in Karnataka state is due its high susceptibility to mosaic, yellow leaf and ratoon stunting. Similarly cv CoC 671 another popular variety of tropical region degenerated due its high susceptibility to mosaic and YL in different parts of Karnataka and Maharashtra. The cv Co 86032 has replaced popular varieties Co 740 and CoC 671 in large areas in these states due to their degeneration. This chapter gives recent findings on the impact of the non-fungal diseases on the performance of sugarcane varieties in the country.

Sugarcane viruses

Yellow leaf (YL) caused by *Sugarcane yellow leaf virus* (SCYLV) and mosaic caused by *Sugarcane mosaic virus* (SCMV) and *Sugarcane streak mosaic virus* (SCSMV) either alone or in combination are the major viral diseases in India. Detailed studies were taken up on the prevalence of these viruses in varieties originated from 11 different states in the country (Viswanathan and Karuppaiah 2010). Reverse transcription polymerase chain reaction (RT-PCR) assays with virus-specific primers were conducted to detect the viruses from more than 60 sugarcane varieties. The results showed that 93.44% of varieties were infected with SCSMV, 31.15% with SCMV and 27.87% with SCYLV. Of the 61 varieties, 47.5% were infected with SCSMV alone, 3.28% with SCMV alone and 4.92% with SCSMV alone. However, 21.3% of them had combined infections of SCSMV and SCMV and similarly 16.4% of them had combined infections of SCSMV and SCYLV. About 6.5% had mixed infections of all the three viruses. Overall, the assay results indicated that SCSMV is predominant among the three viruses and it has been found as a major causative virus of sugarcane mosaic. This study revealed extensive spread of these viruses in sugarcane varieties practically and none of them is free from any of the viruses.

Leaf freckle caused by *Sugarcane bacilliform virus* (SCBV) is a lesser known disease of sugarcane in India. Recent PCR assays with 28 samples for SCBV revealed that the virus is amplified in 75.0% of the samples. Among them 89.5% were commercial cultivars, which revealed that majority of the varieties under cultivation have the virus infection (Karuppaiah 2011). Although impact of this virus on sugarcane growth was not established, its widespread occurrence in the field suggest that it may become a threat in future years.

Impact of yellow leaf

Earlier studies conducted at Sugarcane Breeding Institute (SBI), Coimbatore indicated that drastic reduction in number of millable canes is recorded in sugarcane cvs Co 6511, Co 86032, CoS 687 and CoV 92101 due to SCYLV infection (Viswanathan *et al.* 2006). Previously Viswanathan (2002) showed that the disease infection results in reduction in cane diameter and photosynthetic rate in most of the affected varieties. However, the reduction was significant in CoS 510, CoS 767, CoS 8407 and Co 775. In endemic locations of South India such as Tamil Nadu, Karnataka and Andhra Pradesh diseased canes recorded 37.23% reduction in cane weight, 15.25% in diameter, 5.03% in intermodal length and 19.45% in juice yield from cane (Rao et al. Unpublished). YL 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).

Recently detailed studies were conducted at SBI on the impact of YL 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, unpublished). 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.

Although the crop with mild YL symptoms record normal cane growth in the plant crop, ratoons from such fields show severe disease and ultimately cane yield is reduced. The major impact on YL infection was found on cane thickness and height in sugarcane. In some occasions, the number of internodes is almost same in the infected and healthy plants; they are shorter and lighter in weight in the infected canes. Fresh weights of comparable internodes of the infected plants are only 20-65% of the weight of healthy plants. It is estimated that severe infection of the disease reduces cane yield by 30 to 50 % and sugar recovery is reduced significantly in the mills. Since the loss caused by the disease is phenomenal in the field as well as in the mills, both the cane growers and millers suffer due to the disease.

The causative virus of YL 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 YL-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.

Mosaic viruses

In the past, there were assumptions that mosaic does not cause significant yield loss in sugarcane in the country, 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 was 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. Results of juice analysis revealed that virus infection reduced brix, sucrose per cent, purity and commercial cane sugar per cent in both sugarcane varieties. The results indicated that infection of mosaic viruses in sugarcane severely affects cane growth and sugar yield under field conditions, and sugar recovery to a significant level in the popular varieties (Viswanathan and Balamuralikrishnan 2005). As discussed before, these two varieties went out of cultivation in the tropical region where red rot was not a constraint due to their severity to mosaic. The susceptibility to mosaic in sugarcane varies among the varieties and accordingly the loss to crop growth and yield vary. From subtropical region also, such loss caused by mosaic was reported by many workers. However, such reports were largely ignored in sugarcane due to major losses caused by red rot or wilt during different decades.

Combined infections of RSD and sugarcane viruses

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 YL 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 (2001) revealed that varieties such as Co 99005, Co 99010, Co 99014, Co 92020, 93R5 and CoM 88121 in Mandya region of Karnataka recorded high titre for both *Liefsonia xyli* subsp *xyli* (*Lxx*) and SCYLV and the same entries in the zonal varietal trials were free from *Lxx* at Coimbatore. Observations on sugarcane growth in the trials indicated that the varieties positive to either one or both were stunted severely. The results also revealed that those clones with severe RSD had severe symptoms of YL. Although ELISA study was not conducted at the time to confirm the causal agent of YL, later studies proved that RSD infected sugarcane clones have high titre for SCYLV. These studies suggest that stunting and poor performance of sugarcane clones in different trials as well as in the fields in Karnataka state are primarily due to their susceptibility to RSD and YL. The results further suggest that infection of SCYLV alone in sugarcane may not cause much growth retardation. 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 YL 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 YL 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 separately. Since occurrence of YL 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 studies conducted at SBI showed that phytoplasma infection can cause 35% reduction in stalk height, 15% reduction in stalk girth, 50-60% reduction in length of internodes. Above all 50-75% plant crop infection resulted in 100% failure in millable cane production in the ratoon crop of a clone ISH 152 (Viswanathan, Unpublished).

Detailed molecular studies on the basis of resistance to viruses infecting crop plants revealed a mechanism referred to as "RNA silencing". In this, multiplication of viral genome inside of a host cell is prevented through a specific RNA degradation mechanism. However, some of the viruses evade the RNA silencing surveillance mechanism inside the host cell or develop counter strategies to overcome the silencing. The silencing suppressor proteins are encoded by the viruses to protect them from host RNA silencing machinery. Scientific colleagues from USA and other countries reported silencing suppressor proteins from SCMV and SCYLV (Mangwende et al. 2009; Mirkov et al. 2001). Recently our group has initiated studies on identifying silencing suppressor proteins from sugarcane viruses. Characterization of silencing suppressor proteins such as SCYLV-P0 and SCSMV-Hc-Pro are in progress and the results revealed unique domains in their genome (Viswanathan, unpublished). An important understanding on RNA silencing and silencing suppressor proteins reveals that suppression of host RNA-silencing by a virus would favour infection by another virus. In sugarcane also infection by many viruses may have a synergistic effect and it may cause varietal degeneration. Further studies are in progress to understand the mechanism of varietal degeneration in sugarcane through molecular techniques.

Disease management strategies

The brief review summarized the impact caused by the various diseases on sugarcane growth and yield. Detailed information is provided on non-fungal diseases since it has not been comprehensively reviewed earlier. Also most of the reviews on sugarcane diseases have focussed on important fungal diseases. Availability of molecular diagnostic tools has helped the author and his group to diagnose the suspected pathogens infecting sugarcane and precisely identify them. Some of the key disease management practices to sustain crop productivity in sugarcane specific to Indian situation are discussed here.

Easily available options

Infected planting materials are responsible for the primary spread of the disease in the field. Hence, going for the disease-free setts would reduce the risk of disease introduction to disease free areas. Lack of awareness on seed cane health and ignoring quarantine regulations resulted in introduction of diseases, their epidemics and varietal degeneration in the country. To increase sugarcane productivity, supply of healthy seed canes is to be ensured in the field. As vegetative propagation in sugarcane favours harbouring of the pathogens causing red rot, smut, wilt, grassy shoot, leaf scald, yellow leaf and ratoon stunting in the setts, adequate care should be taken while selecting seed canes. Since it is difficult to detect incipient infections of *C. falcatum* in seed-pieces, it is recommended to take the planting material from a disease free crop. Any crop with more than 5% smut or as high as 2% grassy shoot incidence is unsuitable for seed purpose. For red rot, if there is any infected clump in the field the plot is to be rejected for seed. It is advised to select always a disease free area to raise the seed crop.

Next to healthy seed, sanitation is important in preventing healthy cane from becoming infected with pathogens. Left over sugarcane debris is the prime substrate for the survival and spread of pathogen inoculum especially in the case of red rot, wilt and ratoon stunting. Red rot-infected debris is found to readily infect planted setts and cause death of settlings. Destruction of all plant debris such as cut canes, trash and stubble *in situ* is essential for the reduction of the pathogen inoculum. Further, complete removal of the disease-affected clumps in the field would also ensure disease free field.

Many of the diseases in sugarcane are aggravated by various biotic and abiotic factors. Negligent crop faces different biotic and abiotic factors like different borers, sucking pests, drought or water logging etc. Biotic factors such as infestation of internode borer or *Striga* favours early expression of yellow leaf. Hence, all these biotic stresses are needed to be minimized to reduce the severity of yellow leaf. It is well known that root borer infestation favours wilt outbreaks in different regions. Hence, adequate care should be taken to minimize many of these biotic and abiotic factors which predispose the crop for the infection of different pathogens.

Disease surveillance and diagnosis of sugarcane diseases

Many of the diseases do not cause diagnosable symptoms on the seed cane and different factors influence disease expression in the field hence we need to follow certain diagnostic techniques based on serology or molecular biology to detect them in the seed cane before planting in the field. Effort to detect and diagnose sugarcane pathogens using more advanced laboratory techniques has been developed in the past two decades at SBI, Coimbatore. Diagnostic techniques have been developed against the sugarcane pathogens specific to Indian situation. Specific primers were identified for different viruses and uniplex-, duplex- and multiplex-RT-PCR techniques were developed to detect three RNA viruses indfecting sugarcane either alone or in combinations (Viswanathan et al. 2008, 2010). The RT-PCR technique was found to be sensitive to detect SCYLV in asymptomatic sugarcane and tissue culture seedlings (Viswanathan et al. 2009). Molecular-based diagnostic tests are generally considered to be very sensitive and this is probably their biggest advantage. In addition to detecting sugarcane pathogens in seed canes, the recent approaches in the disease diagnosis using serological and molecular approaches have applications to develop disease-free seedlings, disease surveillance and integrated disease management in sugarcane.

Currently PCR technique is used to index sugarcane materials for grassy shoot infection and RT-PCR technique is used to index sugarcane for SCMV, SCSMV and SCYLV infections. 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 our lab, which is an accredited test laboratory (ATL) for sugarcane virus testing in the country. The molecular tests are highly sensitive to detect very low virus titre in *in vitro* stock culture or in seedlings. Utilization of these molecular techniques will be a boon 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.

Use of resistant varieties

The use of resistant varieties is the most important means of managing sugarcane diseases in a sustainable way. Although frequent breakdown of sugarcane varieties is a cause of alarm, new varieties with high to moderate levels of resistance to the disease are introduced time to time. The varieties Co 86010, Co 86249, Co 93009, Co 94008, Co 95003, Co 97008, Co 99004, Co 99006, CoV 92102, Co 0118, Co 0238, Co 0239, Co 0241 etc are found to be resistant to red rot (Viswanathan 2010). Unlike red rot, smut resistance in commercial varieties in the field is quite stable. Most of the ruling varieties are resistant to smut. However, research institutions should exercise caution while promoting smut susceptible varieties. The author has witnessed severe outbreaks of smut in many parts of Andhra Pradesh where smut susceptible varieties like CoA 92081 or CoV 05356 were grown. The factory authorities should also desist from spreading red rot susceptible varieties although they possess high quality. In the recent past, red rot was recorded in many susceptible varieties like Co 91017, Co 92020, Co 94012, CoSi 6, CoV 94101, PI 96-843 etc in Tamil Nadu and Gujarat. Though such varietal spread is meagre, they provide an ecological niche for the pathogen to survive in the environment. While advocating sugarcane varieties to a factory, care should be taken that there should be a proper varietal distribution in that region. In case of disease outbreaks, the disease spread will be rapid in case of monocropping as there is no barrier to check the disease. Also cultivating a single variety in more than 75% of the area would result in development of highly virulent strain of the pathogen, which may cause more damage to the crop than the existing pathotypes.

Virus elimination

Since many of the viruses are systemically infecting sugarcane, virus elimination through meristem-tip culture is being followed in many countries. *In vitro* culture techniques employed for virus elimination involve indirect morphogenesis. Some viruses can be effectively eliminated from infected plants owing to their mode of replication and their mechanism of movement within the plant. Meristem tip culture is the most widely used method to eliminate the virus/phytoplasmas from sugarcane than thermotherapy and chemotherapy. This technique takes advantage of the fact that many viruses are unable to replicate in this region. Transfer of the meristem dome, together with one or two leaf primordial, to a culture medium and development into a plantlet may lead to the elimination of a virus.

Ever since YL 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. At our conditions, incorporation of nucleic acid analogues like ribavirin improved the efficiency of SCYLV elimination from the infected mother plants (Neelamathi, unpublished). Since these virus elimination techniques are not 100% efficient to eliminate the virus there is a need to index the sugarcane seedlings using precise techniques. At seedlings stage the disease symptoms are not expressed. Also symptom expression in meristem derived plants in the field may be suppressed due to very low titre of the infective virus. We have demonstrated that meristem culture combined with molecular diagnosis was proved to be successful to effectively manage SCYLV. Production of SCYLV-free seedlings has ensured supply of YL-free planting materials to the growers fields and such fields showed renewed vigour in the crop. Overall, virus elimination through meristem culture combined with molecular diagnosis has been demonstrated as a viable strategy to manage YL, which occurred in epidemic form in sugarcane in the recent years (Viswanathan et al. 2011). The technique also ensures elimination of SCGS-phytoplasmas more effective.

Three-tier nursery programme

The practice is in vogue for many years in the country, however, its adoption in different states is very poor. Aerated stream therapy (AST) or moist hot air therapy (MHAT) advocated to eliminate sett borne infections of GSD and RSD. Had this simple practice been followed in the mills, serious outbreak of grassy shoot in many varieties would not be there in the country. The scientific principle involved in heat therapy is that the pathogens present in seed materials are inactivated or eliminated at set temperatures not deleterious for the host tissues. Here functioning of the heating unit and temperature control systems, proper volume and circulation of the heating medium and proper loading of the cane within the treatment chamber are to be monitored time to time. Treated setts should always be treated with fungicides (Carbendazim 0.1%) to reduce the entry of soil pathogens through cut ends. Since operations in treatment units need critical care and handling this treatment is recommended only for raising primary seed in three tier seed nursery programme. The treated setts should always be planted in factory farm for better monitoring. In place of the thermotherapy meristem-culture derived seedlings can also be used in three tier seed nursery programme to get disease-free seedlings.

CONCLUSIONS

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 which is referred as '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. To increase sugarcane productivity in India, supply of healthy seed canes is to be ensured in the field. Research personnel and development workers should be actively involved in creating awareness on supply of healthy seed. In addition to detecting sugarcane pathogens in seed canes, the recent approaches in the disease diagnosis using serological and molecular approaches have applications in the field of developing virus-free seedlings, germplasm exchange and quarantine, disease surveillance and integrated disease management in sugarcane.

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