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BIOLOGY AND MANAGEMENT OF SUGARCANE RED ROT: A REVIEW

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Abstract

Ssugarcane is an important source of income and employment for the farming community of the country. But it is affected by many biotic and a biotic factors which have negative impact on the production and productivity of the crop. Among all the biotic factors, diseases play very important role and amongst all the diseases, red rot is considered as the most devastating and serious disease know as cancer of sugarcane. The cause of the disease is a fungus *Colletotrichum falcatum*. Once the disease is appear in the field, could not be managed by employing one or the other measures until understanding its biology and nature. Therefore the present review summarizes the background, biology and management of red rot disease of sugarcane.

Key words*:* Red rot, *Colletotrichum falcatum,* genetic variability, host resistance, PR proteins, management.

Introduction

Sugarcane (*Saccharum officinarum*.) is an important source of income and employment for the farming community of the country. Sugarcane is a perennial crop which is composed of six species of perennial grasses of the genus *Saccharum* L. In 2013-14, area under sugarcane cultivation was about 5.01 M ha with total 350.02 MT sugarcane production and 245.50 MT sugar production, with the productivity of about 69.84 MT /ha (Anon, 2014 a). Worldwide, Brazil ranked 1st in sugarcane production, while India was the 2nd largest producer of sugarcane (Anon, 2014 b). India's share in world's sugarcane production was 15.39 per cent in 2013-14 (Anon, 2014 a). About 435 sugar mills in different parts of India depend on sugarcane for production of white sugar, ethanol and power generation (from bagasse) (Viswanathan and Samiyappan, 2002). Sugarcane is one of the most important agro-industrial crops of India next to textile industry. It is grown in both tropical and sub-tropical belts of the country, later has a major concern with respect to the total pool of sugar production in the country (Kaur *et al.,* 2014*)*. Productivity of sugarcane is function of many factors such as climate, soil, cultivar and biotic and abiotic stresses. Among these, the losses caused by the diseases are combination of biotic and abiotic stresses which is crucial in nature in reducing the production and productivity of sugarcane. The crop is reported to be affected by 240 diseases from the stage of planting to harvest (Rott *et al.*, 2000). About 55 diseases of sugarcane caused by fungi, bacteria, viruses, phytoplasmas and nematodes have been reported from India (Rao *et al*., 2002). About 10–15 per cent of the nation sugar produced is lost due to the diseases (Viswanathan and Rao, 2011). Of the various biotic stresses of sugarcane, red rot caused by *Colletotrichum falcatum*, is a devastating fungal disease posing a serious threat to sugarcane cultivation in India (Alexander and Viswanathan, 1996). It is also the oldest mentioned disease of sugarcane dating back to the times of Buddha. Red rot is widely distributed and has been reported in 68 sugarcane growing countries of the world (Bharti *et al.,* 2012).The worldwide loss in cane yield and in sugar recovery was about 5–10 per cent (Viswanathan and Samiyappan, 2002).

Disease distribution and economic losses in India

In India, the first documented epidemic of red rot occurred in 1895-1901 and in subsequent years a number of major outbreaks have been recorded as a regular event in the sub-tropical and tropical regions of the country (Satyavir, 2003). These epidemics have resulted in the devastation of local varieties and elimination of many early Coimbatore bred varieties including Co312 and Co453.

The disease essentially confined to northern India, parts of north-western India and Andhra Pradesh for several decades and has started spreading to other parts of southern India as well, especially in the east coast zone, taking a heavy toll of many improved varieties, the most notable one was CoC671. It has resulted in the devastation of the local varieties and elimination of many early hybrid varieties such as Co210, Co213, Co312, Co453, CoJ64 and CoC671 (Natarajan *et al*., 1998). According to Viswanathan and Samiyappan (2000), the red rot disease is widely distributed throughout the tropics, and is one of the most serious diseases in India, Louisiana and Australia; it has been attributed with losses from 25 to 50 per cent of the crop. It has been implicated as a cause for a nation-wide loss of 5–10 per cent in cane yield, making it the most serious threat among the biotic stresses in India and other south Asian countries. In recent times CoJ64, had been the most popular variety because of its highest sugar recovery, was one among the several varieties that succumbed to red rot. The red rot disease is a major constraint for sugarcane production in India and the subcontinent faced many epidemics in the past resulting in elimination of many popular varieties from cultivation. Further Hussnain and Afghan, 2006 reported that this disease causes losses in both cane yield (29.07%) and sugar recovery (30.8%) .It has been reported that this disease became highly destructive in the North western part of the country due to favourable environmental conditions of high humidity and ideal temperature during crop season in this area (Tiwari *et al*., 2010). However, it has also spread to the peninsular parts of the country. This disease appear in in low and sever condition in almost all the sugarcane growing states in India , especially in eastern Uttar Pradesh, Northern Bihar and pockets of Punjab (Babu, *et al*., 2010). However, much higher yield losses of up to 100 per cent from India has been reported when the disease occurred in epidemic form during different decades and many popular varieties like Co419, Co997, Co1148, Co6304, CoS767, Cos87231, CoSe92423, CoC671, CoC85061, CoC92061 and CoJ64 etc. were removed from cultivation (Viswanathan, 2010).

Pathogen

Sugarcane Red Rot is caused by the pathogen *Colletotrichum falcatum* Went (Teleomorph: *Glomerella tucumanensis* [Speg.] Arx and Muller). The fungus belongs to Division- Ascomycota, Class- Sordariomycetes, Order- Glomerellales, Family- Glomerellaceae and Genus- *Colletotrichum*. Abott (1938) characterized different isolates of red rot pathogen into two distinct dark and light races on the basis of colour and texture. He revealed that dark type sporulated sparingly and light type sporulated abundantly and the light type with heavy sporulation was reported as virulent race. Since new races of red rot pathogen appears regularly in nature in the occurrence of two distinct strains, the dark and light types were recognized. The typical morphological and cultural features of *C. falcatum* include acervuli with setae, presence or absence of teleomorph, colony colour, sporulation and growth rate (Viswanathan *et al*., 2003a). This genus is a facultative parasite. Mycelium is immersed, branched, septate , hyaline, pale brown or dark brown. Acervuli are subcuticular, epidermal, sub-epidermal, separate or confluent, composed of hyaline to dark brown, thin or thick walled cells; dehiscence irregular, sclerotia sometimes present in culture, dark brown to black, often confluent, occasionally setose. Setae in acervuli or sclerotia are brown, smooth, septate and acutely pointed at the apex. Conidiophores develops from upper cells of the stroma in a dense, even stand, simple or branched only at the base, aseptate or septate, short hyaline to brown. Conidiogenous cells are phialidic, enterblastic, hyaline, aseptate, straight to falcate, smooth and thin-walled and sometimes apex drawn into a cellular appendage. Appressoria are brown, entire or with crenate to irregular margins, simple or repeatedly germinating to produce complex columns or several closely connected appressoria (Chaube and Singh, 2001). In sugarcane, *C. falcatum* produces host selective phytotoxin and the partially purified toxin produces part of symptoms of the disease and it inhibits callus growth in sugarcane, plantlet differentiation and plantlet growth in tissue culture (Mohanraj *et al.,* 2003). It was reported that the isolates from sub-tropical regions were more virulent than the existing tropical isolates (Kumar *et al.,* 2011). Studies on *C. falcatum* growth and sporulation indicated that the temperature range of 25–30C is ideal for growth and sporulation and the increase in temperature reduces these parameters and at 37 C it completely inhibited the both (Malathi *et al*., 2012). *Colletotrichum* sp. has been differentiated based on phenotypic traits such as mycelia growth rate, characters of conidia and aspersoria, colony appearance and production of setae. The spores germinate and the mycelia get established in bud scales, root primordial or leaf scars and later within the plant tissues. Different isolates of the fungus showed variability in cultural characteristics, fruiting structures and virulence (Bharti *et al.,* 2014). In the subtropical plains of North Uttar Pradesh, the high relative humidity and temperatures during the monsoon period in the month of July-August make genotypes very vulnerable to the attack of *C. falcatum*, resulting in complete devastation of the standing crop. Variability in virulence among the pathotypes has also been reported that red rot pathogen undergoes adaptive changes in relation to the host cultivars cultivated

in subsequent alterations in the virulence patterns of the fungus. Further, it was found that isolates of red rot fungus are often unstable in their pathogenicity and have a tendency to pass irreversibly into a virulent phase. There are 5 major races in India and higher virulence of the tropical isolates as compared to subtropical isolates. *Colletotrichum falcatum* isolates are culturally, morphologically and pathologically dissimilar and six new races are reported in India (Bharti *et al.,* 2014). The average length and width of conidia varied between 27.0-45.0 and 5.6-10.0 ìm, respectively (Kaur *et al.,* 2014). The colour and texture of the mycelia, nature and degree of sporulation appear to be inter-related to some extent with certain conidial characters as well as virulence (Bharti *et al.,* 2014).

Symptoms

In India, the disease is highly destructive in the north-western part of the country due to prevalence of high humidity and temperature. However it has spread to the peninsular parts also. It infects various parts of the sugarcane plant but stalk is more vulnerable. Therefore it is considerable a stalk and seed plant disease (Suman *et al.,* 2005). It attacks the stalks, stubble rhizomes, and leaf midribs of the sugarcane plant. It may invade leaf-blade and leaf-sheath tissues and is capable of infecting sugarcane roots but it is not important as a disease of these organs. Generally symptoms appear on midrib of leaf and stalk. At first, symptoms appear as the death of young and emerging shoots without any conspicuous identifiable symptom in March to May in north Indian condition (Duttamajumder, 2008).

Stalk Symptoms

Symptoms may not be readily apparent in the field, especially in the early stages of the disease. Plants so affected may be detected by the yellowing, shriveling, and drying of the upper leaves. Drying up of margins can be seen at 3rd & 4th leaf from the crown. More certain identification of red rot can be made by splitting the stalk of standing cane. The disease is recognized by the longitudinal reddening of the normally white or yellowish-white internal tissues of the internodes, especially when this red color is interrupted by occasional white spots extending cross wise of the stalk. Brown or reddish brown stripes appear externally at nodal region. Tissues emit alcoholic sour smell. Tiny acervuli develop on outer surface of shrinked upper internodes. Cottony gray fungal mass develops in the pith region of the internodes and sporulates abundantly. Nodal rotting appears when the crop is at the end of the growth phase during August-September in subtropical India. In the early stages of infection, it is difficult to recognize the presence of the disease in the field, as the plant does not display any external symptom or distress. At a later stage, some discoloration of rind often becomes apparent when internal tissues have been badly damaged and are fully rotten. This is more pronounced in the stalk of light colored genotypes. At the end, affected plant dies. At the field level, this may be observed as the death of a few plants or clumps to the failure of entire crop (Duttamajumder, 2008). The most common symptom observed in those fields affected by red rot, was discoloration and yellowing of the young crown leaves. The discoloration and withering continued from the tip to the leaf base until the whole crown withered. The plant died within 10–15 days (Saksena *et al.,* 2013*)*.

Leaf Symptoms

The lesions on the leaf midribs originate as dark reddish areas, which usually elongate rapidly and sometimes extend the entire length of the inner midrib. The young lesions are blood red in color with darker margins. The centers become straw-colored with age and when fructification of the fungus begins, the lesions are covered with black powdery masses of conidia and acervuli with dark reddish brown margins. The lesion from a single point of infection is usually continuous along the midrib, but sometimes it is broken up into a succession of red blotches alternating with apparently healthy tissue. These lesions are 2 to 3 mm in length and about 0.5 mm in width. Occasionally minute red spots on the upper surface of the midrib are also observed .

Transmission of pathogen

Primary transmission of the pathogen is through soil and diseased setts, while the secondary transmission is through air, rain splash and soil. Isolates of the fungus obtained from leaf lesions are capable of producing red rot in the stalks, and the stalk isolates of producing the disease on the leaves. While the conidia produced on the leaves are the principal sources of inoculum for stalk infection, the leaf lesions do not ordinarily initiate stalk lesions by direct mycelial connection. The presence of the spots on the leaves cannot be taken as an indication of its presence in the stalk, nor of the susceptibility of the stalk to the disease. Diseased stalks generate a great deal of inoculums. Dissemination of the inoculums takes place by wind, rain, heavy dews and irrigation water. Infected plant material can readily spread or cause secondary infections. Crop debris or stubble may also provide inoculums to infect a new crop. Although the fungus is not a true soil-borne organism, spores washed into the soil may produce infection in planted seed pieces. Hosts other than sugarcane are not considered important inoculum sources. Climatic factors affect both the spread and severity of red rot. In newly-planted cane, the disease is favoured by excessive soil moisture, drought conditions, and low temperatures. The infected cane setts carry the primary infection to the field. Depending on the nature of

infection and availability of favourable environment, pathogen starts taking toll by killing the bud. This affects the germination and initial establishment of the crop. Poor germination leads to a gappy crop stand and reduction in yield. If, at all, the buds of the infected setts are able to sprout and grow, then only above ground symptoms appear. The type of symptoms varies depending on the prevailing weather conditions.

Diagnosis of the Pathogen

Nithya *et al.,* 2012 developed a polymerase chain reaction (PCR) assay for accurate and sensitive detection of *C. falcatum* in planting materials. Use of serological methods for red rot fungus identification was initiated at Sugarcane Breeding Institute (SBI), Coimbatore, India and good amount of information was generated on serological variation among *C. falcatum* isolates. Polyclonal antiserum were produced against *C. falcatum* pathotypes *viz*. Cf687, Cf997, Cf1148 and Cf86062 (Viswanathan *et al.,* 2000). Viswanathan *et al*.(1998) and Hiremath and Naik (2004) further attempted detection of *C. falcatum* in sugarcane tissues by different serological assays like Enzyme Linked Immune Sorbent Assay (ELISA), Dot Immune Binding Assay (DIBA) and western blotting. The presence of *C. falcatum* was demonstrated by electrophoresing the PCR products on agarose gels. Amplified product of the expected size (~550bp) was obtained from all the tested samples by using ITS-1 and ITS-4 universal primers specific to the fungus ITS region. Therefore, infection of red rot was confirmed through the PCR analysis. The ELISA technique was also useful in assessing the pathogen load at different nodal positions in sugarcane treated with plant growth promoting rhizobacteria (Viswanathan and samiyappan,1999a). Viswanathan *et al*. (2000) demonstrated that infection of sugarcane tissues in stalks could be detected by ELISA technique using polyclonal antiserum raised against the pathogen. This technique enables detection of the pathogen colonization before symptom expression. The DIBA technique is a simple, rapid and specific method for the laboratory analysis of sugarcane (CoC 671) red rot in the early growth stage of the plant and the antigen and primary antibody dilutions of 1:1000 and 1:100, respectively, were found optimum for screening of DIBA technique (Hiermath and Naik, 2004).

Genetic variability of the Pathogen

The pathogen variability in *C. falcatum* was first studied by Edgerton and Moreland (1920) and later it was reported by various workers. Pathogenic variability in *C. falcatum* based on virulent pattern has also been reported by earlier workers who used different sets of differentials using plug and nodal methods of inoculation (Khirbat *et al.,* 1980; Beniwal *et al.,* 1989). Alexander *et al.* (1985) classified *C. falcatum* isolates in India into different pathotypes based on their differential reaction. Subsequent workers reported the existence of different pathotypes of *C. falcatum* using host differentials (Nageswararao and Achutaramarao, 2004; Nageswararao and Patro, 2005). On the basis of these host differentials, Satyavir (2003) summarized Cf 01, Cf 02, and Cf 03 in varieties Co 1148, Co 7717 and CoJ 64, respectively from the North West Zone and Cf 04, Cf 05, and Cf 06 pathotypes in varieties Co 419, Co 997, and CoC 671, respectively, from East Coast Zone. Subsequent studies on pathogenic variability during 1993-2000 revealed the existence of four new pathotypes *viz*., Cf 07, Cf 08, Cf 09 and Cf 10. But all these pathotypes except Cf 09 were virulent on CoS 767. The breakdown of resistance in this cultivar was noticed in Haryana and U.P. in recent years and these studies confirmed the appearance of a new pathotype (Cf 09) capable of breakdown of resistance of this widely cultivated cultivar in North West Zone (Satyavir *et al.,* 2001). Involvement of pectinolytic enzymes with pathogenic virulence has been well documented in *C. falcatum* as many other *Colletotrichum* spp. are having necrotrophic phase (Wijesundera *et al.* 1989). The production of new strains in *C.falcatum* by hybridization could not be ruled out beside mutation (Agnihotri, 1990). In the recent past, various DNA- based characterization methods have been used successfully in identification of different *Colletotrichum* spp. infecting different hosts (Madan *et al*., 2000; Latha *et al*., 2003; Kumar *et al*., 2010). Pathogen variability has been established among the isolates obtained during different periods and locations in India. The isolates were distinguished at morphological, cultural, serological and pathogenicity level (Viswanathan *et al.,* 2003a) and at molecular level by Random Amplified Polymorphic DNA (RAPD) (Mohanraj *et al.,* 2002; Suman *et al.,* 2005). The pathogen undergoes adaptive changes in relation to the host varieties cultivated, which subsequently leads to alterations in the virulence pattern of the fungus (Satyavir, 2003; Duttamajumdar, 2008). Different pathogens have been reported to possess a high degree of molecular variability when evaluated by RAPD markers in case of *C. falcatum* (Guerber *et al.,* 2003; Whitelaw *et al.,* 2007) and *C. gloeosporioids* (Telhinhas *et al.,* 2005). *Colletotrichum* spp. infecting diverse hosts have a high degree of pathogenic variability (Sharma *et al*., 2005). It is inferred that existence of minimal variability among *Colletotrichum falcatum* isolates could be mainly due to adaptability of these isolates to newer cultivars (Malathi *et al.,* 2006). *C. falcatum* pathotypes exhibit distinct differential host interaction where certain pathotypes specifically infect their adapted host cultivars. Pathogenicity of Cf1148 and Cf7717 isolated from cultivars Co1148 and Co7717, respectively, influenced by their

respective host specific parental cultivars and not vice versa. Development of light isolates and reduced latent period for symptom expression by repeated inoculations on incompatible hosts indicated the increased virulence or pathogenicity of that pathotype for adaptation on a particular cultivar (Malathi *et al.,* 2006). Recently, phylogenetic relationship has been established among the isolates from all the major red rot endemic regions in India, using conserved gene sequences *viz*., 5.8s-ITS, actin, calmodulin and glyceraldehyde 3-phosphate dehydrogenase (Malathi *et al.,* 2011). Genetic difference between twelve red rot resistant and five susceptible genotypes of sugarcane cultivated in Pakistan were studied using RAPD markers and found that the resistance or susceptibility to red rot in modern sugarcane hybrids is due to more than one genetic reason (Alvi *et al.,* 2008). Investigation, showed the high molecular diversity of the red rot isolates (Cf 01, 02, 03, 07, 08, 09) through the RAPD, Universal Rice Primers (URP) and Inter- Simple Sequence repeat (ISSR) markers from different commercial varieties grown in north India (Kumar *et al.,* 2010). Studies indicate that the pathogenic virulence has positive correlation with quantity and quality of toxin and the symptoms produced by it (Malathi and Vishwanathan, 2012). Cultural studies indicated that *C. falcatum* virulence related factors *viz*., growth, sporulation and conidial germination had negative correlation with the host resistance and positive correlation with sucrose content in various sugarcane varieties. Production of melanin during host pathogen interaction was found to have a positive relation with virulence when pathogenicity assay was conducted in stalks and leaves (Malathi and Viswanathan, 2012).Variable symptoms on genotypes infected by *C. falcatum* and variation may be related to development of new races. The least virulent strains were Cf03 and Cf11, infecting only 3 varieties and widely spreading nature of the pathotype Cf08 in northern area. It may also be concluded that the isolate Cf 08 is more harmful for newly developed varieties. The analysis clearly indicated the genetic diversity of the *Colletotrichum falcatum* isolates collected from the different regions of the Uttar Pradesh (Saksena *et al.,* 2013*)*. Based on the disease severity, isolates Cf-157, Cf-245, Cf-248 and Cf-249 were found the most virulent (71.43% virulence frequency) followed by Cf-254 (64.28%) whereas isolate Cf-60 was the least virulent (28.58%). However, it also inferred that morphological grouping of most of the isolates possess positive correlation with pathogenic variability whereas molecular diversity did not showed such correlation (Kumar *et al.*, 2014).

Management

Management strategies to reduce the red rot severity of the disease under field conditions have not yielded satisfactory results (Viswanathan *et al.,* 1997). Although there are many practices which are adopted for management of the red rot disease but it is difficult to manage the disease even with the systemic fungicides or with other method singly due to presence of fiberous nodes, impervious nature of rind, besides water and sugar content in the setts that do not allow the absorption of fungicides to the required concentration that is sufficient to kill the pathogen at the site of infection (Agnihotri, 1990). Integrated disease management (IDM) is one of the best methods for the management of the pathogen. IDM practices reduce red rot incidence, enhance growth parameters and quality attributes of sugarcane compared to Non- IPM practices. Different biocontrol agents have been integrated with cultural practices, soil solarization, fungicides and disease resistant varieties for the management of various diseases in different crops (Mukhopadhyay, 1996). IDM combines all the methods of management which are as following:

1. Agronomic and cultural practices

Red rot incidence can be minimized by crop rotation. Mono cultivation of the same crop as well as variety results in building up of the inoculum leading to the disease development. The crop must be rotated after two to three years and ratooning should be discouraged. The diseased leaves fallen in the field after withering and drying, must be collected and burnt. Sugarcane field should be properly levelled and cultivation conditions should be hygienic.

2. Physical treatment

Infected planting materials are the major source of pathogen inoculums for the annual recurrence of red rot disease (Viswanathan and Alexander, 1997). Use of disease free setts is the most useful method for control of the pathogen. According to the geographical origins, of the isolates could not be correlated with molecular and pathological diversity, since one of the most efficient ways to prevent this devastating disease is through the use of pathogen-free planting materials in commercial production (Jain and Chahal, 2011).

Moist hot air treatment (MHAT at 54 C; 4 hrs) is although effective for the inactivation of superficial infection (Singh, 1973) but it is difficult to eliminate the deep-seated infection of the pathogen inside the cane. The incidence of red rot can be reduced through good cultural practices, such as clearing fields of excessive trash and efficient drainage. Agronomic practices that hasten germination are important in reducing seed rotting and obtaining good stands. Regular rouging of diseased plants, burning of trash, plough out badly affected fields, maintenance of proper soil moisture, and prompt harvesting of infected or susceptible crops are other

management practices recommended for red rot control.

3. Biological control

Of the various control measures in vogue, biological control appears to be the best solution for long term sustainability and effective management of soil-borne diseases (Fravel, 2005). Different bio-control agents have been integrated with cultural practices, soil solarization, fungicides and disease resistant varieties for the management of various diseases in different crops (Gogoi *et al.,* 2007). These bio-agents either work alone or in combination with other methods of management.

Biological control with *Pseudomonas* sp.

Among the potential bacterial antagonists associated with the plant roots, the fluorescent pseudomonads FPs (also known as plant growth promoting rhizobacteria, (PGPR) have received prominent attention due to their abundance in the plant rhizosphere. Apart from direct antagonistic activity against fungal and bacterial pathogens in plants, the FPs has been shown to induce systemic resistance in plants against some pathogens. Induced systemic resistance (ISR) by definition refers to protection of the plants systemically following induction within inducing agent to a single part of the plant (Kloepper *et al.,* 1992). PGPR belonging to FPs induces systemic resistance (ISR) against *C. falcatum* Went causing red rot disease in the sugarcane stalks by three different resistance evaluation methods. All the tested PGPR strains have significantly reduced the disease development in the stalks and, strains of *Pseudomonas* spp. induce systemic resistance against *C. falcatum* causing red rot in sugarcane (Viswanathan and Samiyappan, 1999). The bacterial strains significantly reduced red rot pathogen colonization in the stalk tissues and disease progress was checked (Viswanathan and Samiyappan, 1997 and 1999). Sett treatment followed by soil application of bacterial strains has also reduced the red rot disease development in the crop in pathogen-sick soil. Setts treatment with bacterial strains to pathogen infected setts resulted in higher germination of setts as compared to the untreated setts. These information suggest that the bacterial strains in addition to induced systemic resistance effect in the host, have direct antagonistic activity against the pathogen (Viswanathan and Samiyappan, 2000a). The efficient bacterial strains KKMI *(P. Putida* Trevisan, 1889) and YPT4 (*P. Fluorescens* Migula, 1895) were found inducing systemic resistance in sugarcane cultivar CoC 671, susceptible to red rot disease caused by the fungus *C. falcatum.* Sett treatment with bacterial strains induces higher accumulation of chitinase in the germinating settlings. Induction of new chitinases in the *Pseudomonas* treated sugarcane in response to *C. falcatum* infection indicates that the induced chitinases have a definite role in suppressing the disease development in the stalk tissues (Viswanathan and Samiyappan, 2001). No disease development or less than 1 per cent disease was recorded in the bacteria treated plots (Viswanathan and Samiyappan, 2002). Three bacteria and their isolates were showed antagonistic effect against the red rot pathogen of sugarcane *C. falcatum* by inhibiting fungal mycelial growth under *in vitro* conditions, these were isolates 687-2bl, 71-1-1a and 46-1a2 belonged to *P. aeruginosa* (Schroeter1872) Migula 1900*,* three isolates *viz*. SS1, SS2 and SS3 belonged to *P. fluorescens* and one isolate *viz*. 312-2b, of *P. putida* (Vishwanathan, *et al.,* 2003). The sett treatment while planting and soil application twice in the field with the strains of *Pseudomonas fluorescens* such as EP1, Pfl and CHAO and *P. putida* strain KKM1 strongly suppressed the red rot development and the efficacy of PGPR strains against red rot pathogen, enhanced cane and sugar yields suggest that these bacterial strains could be exploited for management of red rot in sugarcane (Senthil, *et al.,* 2003). Bacterial cells grown on chitin-containing medium showed enhanced antifungal activity against *C. falcatum*, causing red rot disease in sugarcane (Viswanathan and Samiyappan, 2007). In iron deficient medium, most of the bacterial strains produced siderophores and exhibited strong antagonism against *C. falcatum*. In field studies, *Pseudomonas* strains CHAO, EP1, KKM1 and VPT4 induced systemic resistance against red rot pathogen in disease susceptible cultivar. These strains were also effective in suppressing red rot development in sugarcane from the pathogen propagules surviving in the soil (Viswanathan and Samiyappan, 2007).

Biological control with *Beauveria bassiana*

Antagonistic entomopathogenic fungal strains ARSEF-6646, ARSEF-6647, ARSEF-6648, ARSEF-6650 and ARSEF-2417 of *Beauveria bassiana* (Bals.-Criv.) Vuill producing chitinolytic enzymes and caused a higher level of lysis of the pathogen mycelium and suppress the *C. falcatum*, red rot pathogen of sugarcane., and the inhibitory effect was more pronounced when the lytic enzymes were produced using chitin as carbon source (Sanivada and Challa, 2014).

Biological control with *Trichoderma* sp.

Singh (1994) reported that sett treatment or foliar spray with *Trichoderma harzianum* Rifai and *Chetomium* sp. improved germination and were effective against red rot disease development in the field. Antagonistic *T. harzianum* $\mathbf{T_5}$ caused a higher level of lysis of the pathogen mycelium, and the inhibitory effect was more pronounced when the lytic enzymes were produced using chitin or cell wall of the pathogen as carbon source. Lytic enzymes of bacterial strains AFG2, AFG4, VPT4 and FP7 and *T. harzianum* $\mathbf{T_5}$ inhibited conidial germination and mycelial growth of *C. falcatum*

(Viswanathan *et al.,* 2003c). *Trichoderma harzianum* is useful for management of red rot and cultivation of moderately resistant varieties for several years. The protection offered might be due to direct parasitic action of *T. harzianum* on *C. falcatum* and also systemic resistance induced in sugarcane. Application of it is also useful for reducing the economical losses in susceptible varieties. The yield was also enhanced by 15-20 t/ha due to improved germination and shoot biomass. Application of *Trichoderma* biopesticide is eco-friendly, economical and efficient for improving soil health also (Singh *et al.,* 2008). Red rot of sugarcane can be managed by the application of *T. harzianum* since it acts directly on *C. falcatum* and induces systemic resistance in plants developed from treated setts (Yadav *et al.,* 2008).The application of *Trichoderma* multiplied culture (TMC) of *T. harzianum* strain Th 37 @ 20 kg/ha on the stubbles at the ratoon initiation stage increased the availability of nitrogen (N), phosphorus (P) and potassium (K) by 27, 65 and 44per cent, respectively and the level of protection against red rot increased up to 78 per cent in combination with TMC + salicylic acid (SA) and 86 per cent with metabolites + SA where as the protection was 60 and 71per cent, respectively, with TMC and metabolites (Singh *et al.,* 2010).

Bioagents with fungicides

For managing red rot of sugarcane through integrated approach, studies were conducted on compatibility of biocontrol agents with fungicides against the pathogen *C. falcatum*. Antagonistic activity of *Trichoderma* strains was influenced by addition of 1 ppm thiophanate methyl, which resulted in enhanced suppression of *C. falcatum* growth. Fungicide at lower concentration improved the antagonistic potential of *Trichoderma* spp., which might be due to weakening of pathogen by fungicide (Malathi *et al*., 2002). *Trichoderma viride* (bio-agent) in combination with MHAT and fungicidal treatment (carbendazim) (IDM practice) over normal package of practice (Non-IDM practice) of cane cultivation on red rot incidence, yield and quality parameters of sugarcane in a moderately red rot susceptible variety was high in IDM treated plot (Singh *et al.,* 2008).

4. Host resistance

Red rot resistance in various sugarcane species *viz*. *Saccharum officinarum* L., *S. Barbari* Jesw., *S. Sinense* L., *S. Robustum* E.W. Brandes & Jeswiet ex Grassl, *S. Spontaneum* L. *and Erianthus* sp. is being transferred to parents through inter/intra specific or inter-generic crosses (Alexander and Rao, 1972). *Saccharum spontaneum* has been the major source of resistance than other species and *S. officinarum,* the cultivated species has very low level of resistance. Studies of Malathi *et al*. (2012) on screening of red rot resistance in germplasm revealed that the source of resistance is high in *S. barberi* clones followed by *S. sinense* and then *S. robustum*. While *S. officinarum* clones had very low level of resistance among all *Saccharum* spp. This confirms the differential interaction with different pathotypes. Two crosses involving susceptible parents *viz*., 971235 (S) × Co 1148 (S) and Co 88028 (S) × Co 775 (S) contributed 28-30 per cent resistant progenies. These transgressive segregants are likely to be stable in their resistance due to additive genetic action (Babu, 2009).

5. Chemical treatment

Foliar fungicides have not been effective in the control of red rot. However, better crop stands have been achieved from enhanced germination obtained by treating seed pieces with a fungicide before planting. The organo mercurials like Aretan, Agallol (0.25%) for a 5-10 minutes dip helps in the eradication of superficial inoculum and not deep seated mycelium. Some antifungal compounds like thiophanate methyl with trade name Topsin-M are specific against the red rot pathogen *C. falcatum* (Satyavir, 2003). This treatment reduces the incidence of red rot infection in the treated seed piece. Among fungicides under investigation Benomyl 50 WP, Radomil 75 WP and Folicar were found to be most effective in suppressing the pathogen (Subhani *et al.,* 2008). Sugarcane synthesizes a complex mixture of phytoalexins as luteolinidin and apigeninidin in response to inoculation with *Colletotrichum falcatum*, causative agent of red rot, suggest the possible role of these compounds in red rot resistance (Viswanathan *et al.,* 1994). The applicability of plant-based extracts for the suppression of sugarcane red rot disease in the field as an environment-friendly tool in combination with antagonists (Jayakumar *et al.,* 2007).

Conclusion and Future Perspectives

Sugarcane is an important crop of India but diseases are the major concern for the sugarcane, responsible for its low yield. Red rot of sugarcane is the most threatening disease of sugarcane, rightly called as 'Cancer' of sugarcane (Sharma and Tamta, 2015). Various management practices like developing disease resistant varieties, use of pathogen free seed and different fungicides have been adopted to combat the disease but every approach has certain limitations like the newly developed resistant varieties become susceptible to new races of the pathogen which develop due to excessive use of pesticide. The use of pathogen free seed is effective but the pathogen usually penetrates into field through irrigation. Few fungicides are effective in controlling disease but they are banned due to health hazardous effects. Hence, there is extreme need to

develop any alternate management strategies to control the disease and minimize yield losses of sugarcane. Heading towards the Integrated Disease management programme to manage the red rot disease will be the best option for control of the disease. Integration of IDM practices reduced red rot incidence, enhanced growth parameters and improved quality attributes of sugarcane. Besides this, new approaches should be developed to control the disease and exploitation of induced systemic resistance and systemic acquired resistance require more research work to be done further.

References

Abbott, E.V. (1938). Red rot of sugarcane. U.S. Department of Agriculture Technical Bulletin, **641**: 96.

Agnihotri, V.P. (1990). Diseases of Sugarcane and Sugarbeet. Oxford & IBH Pub. New Delhi, 283.

Alexander, K.C. and M.M. Rao (1972). Comparative evaluation of genotypes in the centres in India for resistance to red rot and smut. Proceedings of Diamond Jubilee Symposium of Sugarcane Breeding Institute, Coimbatore.12-24.

Alexander, K.C., M.M. Rao and D. Mohanraj (1985). Disease reaction catalogue on genetic resources II. Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India. 226.

Alexander, K.C. and R. Viswanathan (1996). Major diseases affecting sugarcane production in India and recent experiences in quarantine. *In:* Croft, B.J., Piggin, C.M., Wallis, E.S., Hogarth, D.M. (Eds.), Sugarcane Germplasm Conservation and Exchange, Proceedings 67. Australian Centre for International Agricultural Research, Canberra, 46–48.

Alvi, A.K., J. Iqbal, A.H. Shah and Y.B. Pan (2008). DNA based genetic variation for red rot resistance in sugarcane. *Pak. J. Botany,* **40(4)**: 1419-1425.

Anonymous (2014a). Directorate of economics and statistics, Department of Agriculture and cooperation, GOI. 251.

Anonymous (2014b). United States Department of Agriculture. Retrieved on 10 April, 2015.

Babu, C., K. Koodalingam, U.S. Natarajan, R.M. Shanthi and P. Govindaraj (2009). Genetic enhancement of sugarcane (*Saccharum* sp. Hybrids) for resistance to red rot disease and economic traits. *The Journal of Agricultural Science,* **4(3)**: 97-107.

Babu, C. (2010). Pre-Breeding In Sugarcane (*Saccharum* Sp. Hybrids) For Red Rot Resistance and Economic Traits. *Electronic Journal of Plant Breeding,* **1**: 1024-1034.

Beniwal, M.S., Satyavir and K.S. Virk (1989). Pathogenic variability in *Colletotrichum falcatum* incitant of red rot of sugarcane. *Indian Phytopathology,* **42**: 95-99.

Bharti, Y.P., A. Kumar, D.D.K. Sharma, S.K. Singh and D.N. Shukla (2014). Morphological, physiological and pathological variations among isolates of *Colletotrichum falcatum* that cause red rot of sugarcane. *African Journal of Microbiology Research,* **8(10)**: 1040-1049.

Bharti, Y.P., S.K. Vishwakarma, A. Kumar, A. Singh, M.L. Sharma and D.N. Shukla (2012). Physiological and Pathological Aspects of Some New Isolates of *Colletotrichum falcatum* Causing Red Rot Disease in *Saccharum* sp Complex. *Acta Phytopathologica et Entomologica Hungarica,* **47(1)**: 35-50.

Chaube, H.S. and R. Singh (2004). Introductory Plant Pathology. 1st ed. Lucknow, Army Printing Press. 444p.

Duttamajumdar, S.K. (2008). Red Rot of Sugarcane. Lucknow, India, Indian Institute of Sugarcane Research. 46p.

Edgerton, C.W. and C.C. Moreland (1920). Effect of Fungi On The Germination of Sugar Cane. Baton Rouge, La.: Agricultural Experiment Station of The Louisiana State University and A., M. College.

Fravel, D.R. (2005). Commercialization and implementation of biocontrol. *Annual Review of Phytopathology,* **43**: 337-350.

Gogoi, R., M. Saikia, R. Helim and Z. Ullah (2007) . Management of potato diseases using *Trichoderma viride* formulations. *Journal of Mycology & Pant Pathology,* **37(2)**: 227-230.

Guerber, J.C., B. Liu, J.C. Corell and P.R. Johnston (2003). Characterization of diversity in *Colletotrichum acutatum* sensu lato by sequence analysis of two gene introns, mt DNA and intron RFLPs, and mating compatibility in sugarcane in response to infection by *Colletotrichum falcatum* causing red rot disease. *Journal of Plant Diseases and Protection,* **112 (5)**: 417–425.

Hiermath, L. and R.G. Naik (2004). Rapid diagnosis of sugarcane red rot by Dot-immunobinding assay (DIBA) technique. *Indian Journal of Biotechnology,* **3**: 542-545.

Hussnain, Z. and S. Afghan (2006). Impact of major cane diseases on sugarcane yield and sugar recov ery. Annual Report, Shakarganj Sugar Research Institute, Jhang, Pakistan.

Jayakumar, V. and R. Bhaskaran (2007). Potential of plant extracts in combination with bacterial antagonist treatment as biocontrol agent of red rot of sugarcane. *Canadian Journal of Microbiology,* **53(2)**: 196-206.

Kaur, R., B. Kumar, Y. Vikal and S. Gulzar (2014). Genetic diversity among *Colletotrichum falcatum* Isolates Causing Red Rot of Sugarcane in Subtropical Region of India. *Notulae Scientia Biologicae,* **6(3)**: 308-315.

Khirbat, S.K., Satyavir and M.S. Beniwal (1980). Physiological and pathological variability in sugarcane red rot pathogen, *Colletotrichum falcatum* in Haryana. *Indian Phytopathology,* **33**: 296-99.

Kloepper, J.W., S. Tuzun and J. Kuc (1992). Proposed definitions related to induced disease resistance. *Bio Control Science and Technology,* **2**: 349–351.

Kumar, N,, J. Tripta, S. Satyavir and R.S. Tilak (2011). Molecular and Pathological Characterization of *Colletotrichum falcatum* Infecting Subtropical Indian Sugarcane. *Journal of Phytopathology,* **159(4)**: 260-267.

Kumar, G.V., R. Viswanathan, P. Malathi, M. Nandakumar and A. Ramesh Sundar (2014). Differential induction of 3-deoxyanthocyanidin phytoalexins in relation to *Colletotrichum falcatum* resistance in sugarcane. Sugar Tech.1-9.

Kumar, N., T. Jhang, Satyavir and T.R. Sharma (2010). Molecular

and pathological characterization of *Colletotrichum falcatum* Infecting subtropical Indian sugarcane. *Journal of Phytopathology,* **154 (4)**: 260–267.

Latha, J., A. Chakrabarti, K. Mathur, V.P. Rao, R.P. Thakur and P.K. Mukherjee (2003). Genetic diversity of *Colletotrichum graminicola* isolates from India revealed by restriction analysis of PCR-amplified intergenic spacer region of nuclear rDNA. *Curr. Sci.,* **84**: 881-883.

Madan, V.K., M. Bikas, M.L. Ansari, A. Srivastava and N. Soni (2000). Rapd-Pcr Analysis of Molecular Variability In The Red Rot Pathogen (*Colletotrichum falcatum*) of Sugarcane. *Sugarcane International,* **3**: 5-8.

Malathi, P. and R. Viswanathan (2012). Variation in *Colletotrichum falcatum*-Red rot pathogen of sugarcane in relation to host resistance. *Sugar Tech.,* **14(2)**: 181–187.

Malathi, R., R. Viswanathan and R. Jothi (2006). Specific Adaptation of *Colletotrichum falcatum* Pathotypes to Sugarcane Cultivars. *Sugar Tech.,* **8(l)**: 54-58.

Malathi, P., R. Viswanathan, P. Padmanaban, D.Mohanraj and A. Ramesh (2002). Compatibility of biocontrol agents with fungicides against red rot disease of sugarcane. *Sugar Tech.,* **4(3&4)**: 131 – 136.

Malathi, P., R. Viswanathan, A. Ramesh Sundar, P. Padmanaban, N. Prakasam, D. Mohanraj and R. Jothi (2011). Phylogenetic analysis of *Colletotrichum falcatum* isolates causing red rot in sugarcane. *Journal of Sugarcane Research,* **1(1)**: 69-74.

Mohanraj, D., P. Padmanabhan and M. Karunakaran (2003). Effect of phytotoxin of *Colletotrichum falcatum* Went (*Physalospora tucumanensis*) on sugarcane in tissue culture. *Acta Phytopathol Entomol Hung,* **38**: 21–28.

Mukhopadhyaya, A.N. (1996). Recent innovations in plant disease control by eco-friendly bio-pesticides. Presidential Address in Agricultural Sciences Section, 83rd Indian Science Congress, Patiala, Promoting Rhizobacteria against Red Rot Disease in Sugarcane. *Sugar Tech,* **1(3)**: 67 -76.

Nageswararao, G.V., T.S.S.K. Patro (2005). Pathotypes in *Colletotrichum falcatum* Went. and identification of resistant sugarcane clones. *Journal of Mycology and Plant Pathology,* **35**: 305-309.

Nageswararao, G.V. and M. Achutaramarao (2004). Occurrence of a new virulent pathotype of *Colletotrichum falcatum* on sugarcane in Andhra Pradesh. *Journal of Mycology and Plant Pathology,* **34**: 119-121.

Natarajan, U.S, T.C.R. Rao, N. Balasundaram, K. Palanichamy and B.K. Tripathi (1998). Red rot resistance in sugar cane - a critique. *Sugar Cane,* **1**: 11-14.

Nithya, K., Bukhari Kaim, V. Valluvaparidasan, V. Paranidharan and R. Velazhahan (2012). Molecular detection of *Colletotrichum falcatum* causing red rot disease of sugarcane (*Saccharum officinarum*) using a scar marker. *Annals of Applied Biology,* **160**: 168-173.

Rao, G.P., R. Viswanathan and S.B. Singh (2002). Current situation of sugarcane diseases in India. *In*: Sugarcane crop management. *Eds*. SB Singh, GP Rao, S. Easwaramoorthy, 734. Houstan: SCI Tech Publishing LLC.

Rott, P., R. Bailey, J. Comstock, B. Croft and A.S. Saumtally (2000). A Guide to Sugarcane Diseases. Cirad. Issct, Cirad Publications Services, Montepellier, France 339.

Saksena, P., S. Kumar, S.K. Vishwakarma, A.K. Tiwari, A. Singh and A. Kumar (2013). Pathological and molecular variation in *Colletotrichum falcatum* Went isolates causing red rot of sugarcane in the northwest zone of India. *Journal of Plant Protection Research,* **53**: 37-41.

Sanivada, S.K. and M. Challa (2014). Mycolytic effect of extracellular enzymes of entomopathogenic fungi to *Colletotrichum falcatum*, red rot pathogen of sugarcane. *Journal of Biopesticide,* **7**:33-37.

Satyavir (2003). Red rot of sugarcane current scenario. *Indian Phytopathology,* **56**: 245–254.

Satyavir, N. Singh, K.S. Virk, G.V. Nageswarrao, H. Singh and S.R. Mishra (2001). Pathogenic variability in sugarcane red rots system. S. Nagarajan, OP Singh (*Eds)* In: Proceeding of National Symposium Role of Resistance in Intensive Agriculture, Kalyani Publishers, Ludhiana,109-114.

Senthil, N., T. Raguchander, R. Viswanathan and R. Samiyappan (2003). Talc formulated fluorescent *Pseudomonads* for sugarcane red rot suppression and enhanced yield under field conditions. *Sugar Tech.,* **5(l&2)**: 37–43.

Sharma, P.N., M. Kaur, O.P. Sharma, P. Sharma and A. Pathania (2005). Morphological, pathological and molecular variability of *Colletotrichum capsici*, the cause of fruit rot of chillies in the subtropical region of north western India. *J. Phytopathol,* **153**:232-237.

Sharma, R. and S. Tamta (2015). A Review on Red Rot: The "Cancer" of Sugarcane. *Plant Pathology & Microbiology,* 1-8.

Singh, K. (1973). Hot air therapy against red rot of sugarcane. *Plant Disease Report,* **57**:220-222.

Singh, G., S.K Sandhu, M. Madhu, K. Singh, R. Gill and S.S. Gosal (2008). *In vitro* induction and characterization of somaclonal variation for red rot and other agronomic traits in sugarcane. *Euphytica,* **160**: 35–47.

Singh, N. (1994). *Trichoderma harzianum* and *Chaetomium* sp. as potential biocontrol fungi in management of red rot disease of sugarcane. *Journal of biological control,* **8:** 65-67.

Singh, V., B.B. Joshi, S.K. Awasthi and S.N. Srivastava (2008). Eco-friendly management of red rot disease of sugarcane with *Trichoderma* strains. *Sugar Tech.,* **10(2)**: 158-161.

Singh, V., P.N. Singh, R.L. Yadav, S.K. Awasthi, B.B. Joshi, R.K Singh, R.J. Lal and S.K. Duttamajumder (2010). Increasing the efficacy of *Trichoderma harzianum* for nutrient uptake and control of red rot in sugarcane. *Journal of Horticulture and Forestry,* **2(4)**: 66-71.

Subhani, N.M., A.M. Chaudhry, A. Khaliq F. and Muhammad (2008). Efficacy of Various Fungicides against Sugarcane Red Rot (*Colletotrichum falcatum*). *International Journal of Agriculture & Biology,* **10(6)**: 725-727.

Suman, A., S. Lal S, A.K. Shasany, A. Gaur and P. Singh (2005). Molecular Assessment of Diversity Among Pathotypes of Colletotrichum Falcatum Prevalent In Sub- Tropical Indian Sugarcane. *World Journal of Microbiology and*

Biotechnology, **21**: 1135-1140.

Telhinhas, P., S. Sreenivasaprasad, N.J Martins and H. Oliveira (2005). Molecular and phenotypic analysis reveals association of diverse *Colletotrichum acutatum* groups and low level of *C. gloeosporioides* with olive anthracnose. *Applied Environmental Microbiology,* **71**: 2987-2998.

Tiwari, A.K., Y.P. Bharti , N. Mishra, S. Tripathi, M. Lal, P.K. Sharma, G.P. Rao and M.L. Sharma (2010). Biotechnological Approaches for Improving Sugarcane Crop with Special Reference to Disease Resistance. *Acta Phytopathologica et Entomologica Hungarica,* **45(2)**: 235–249.

Viswanathan, R. (2010). Plant disease: red rot of sugarcane, 306. New Delhi, Anmol Publishers.

Viswanathan, R. and K.C. Alexander (1997). Management of sugarcane diseases. *Indian Journal of Sugarcane Technology,* **12**: 37-48.

Viswanathan, R., P. Malathi and P. Padmanaban (2003a). Variation in sugarcane red rot pathogen *Colletotrichum falcatum* Went. *In*: Rao GP, Manoharachari C, Bhat DJ, Rajak, RC, Lakhanpal TN (eds.) Frontiers of Fungal Diversity in India, 39-67.

Viswanathan, R., D. Mohanraj, P. Padmanaban and K.C. Alexander (1994). Possible role of red rot pigments in host-pathogen interaction in sugarcane with red rot pathogen. *Indian Phytopathol,* **47**: 281.

Viswanathan, R., P. Padmanabhan and D. Mohanraj (1997). Growing virulence of red rot pathogen of sugarcane in Tamil Nadu. *Indian Sugar,* **47**: 23 -30.

Viswanathan, R., P. Padmanaban, D. Mohanraj and R. Jothi (2000). Indirect-ELISA technique for the detection of the red rot pathogen in sugarcane (*Saccharum* spp. hybrid) and resistance screening. *Indian Journal of Agriculture Science,* **70(3)**: 8-11.

Viswanathan, R. and G.P. Rao (2011). Disease scenario and management of major sugarcane diseases in India. *Sugar Tech,* **13(4)**: 336-353.

Viswanathan, R. and R. Samiyappan (1997). Plant growth promoting rhizobacteria for the management of red rot disease in sugarcane. *In:* Proceedings of the International Symposium on Integrated Disease Management for Sustainable Agriculture. New Delhi, India, November 10–November 15, 1997. Indian Phytopathological Society, New Delhi, 458.

Viswanathan, R. and R. Samiyappan (1999a). Induction of systemic resistance by plant growth promoting rhizobacteria in sugarcane against red rot disease. *Sugar Tech,* **1**: 67–76.

Viswanathan, R. and R. Samiyappan (1999b). Induced systemic resistance by fluorescent Pseudomonads against red rot disease of sugarcane caused by *Colletotrichum falcatum. Crop Protection,* **21**: 1–10.

Viswanathan, R. and R. Samiyappan (2000a). Efficacy of *Pseudomonas* strains against soil borne and sett borne inoculum of *Colletotrichum falcatum* causing red rot disease in sugarcane. *Sugar Tech.,* **2(3)**: 26 - 29.

Viswanathan, R. and R. Samiyappan (2000b). Red rot disease in sugarcane: challenges and prospects. *Madras Agricultural Journal,* **87**: 549-59.

Viswanathan, R. and R. Samiyappan (2001). Antifungal activity of chitinases produced by some fluorescent pseudomonads against *Colletotrichum falcatum* Went causing red rot disease in sugarcane. *Microbiological Researches,* **155**: 309-314.

Viswanathan, R. and R. Samiyappan (2002). Induced systemic resistance by fluorescent pseudomonads against red rot disease of sugarcane caused by *Colletotrichum falcatum. Crop Protection,* **21**: 1–10.

Viswanathan, R. and R. Samiyappan (2007). Siderophores and iron nutrition on the *Pseudomonas* mediated antagonism against *Colletotrichum falcatum* in sugarcane. *Sugar Tech.,* **9(1)**: 57-60.

Viswanathan, R., R. Samiyappan and P. Padmanaban (1998). Specific detection of *Colletotrichum falcatum* in sugarcane by serological techniques. *Sugar Cane,* **3**: 18-23.

Viswanathan, R., R.A. Sundar and M.S. Premkumari (2003c). Mycolytic effect of extracellular enzymes of antagonistic microbes to *Colletotrichum falcatum*, red rot pathogen of sugarcane. *World Journal of Microbiology & Biotechnology,* **19**: 953–959.

Went, F.A.F.C. (1893). Het Rood Snot (Summary in English). *Archiefvoor De Java Suikerindustrie,* **1**: 265-282.

Whitelaw, M.A.W., S.J. Curtin, R. Huang, C.C. Steel, C.L. Blanchard and P.F Roffey (2007). Phylogenetic relationships and pathogenicity of *Colletotrichum acutatum* isolates from grapes in subtropical Australia. *Plant Pathology,* **56**: 448-463.

Wijesundera, R.L.C., J.A. Bailey, R.J.W. Byrde and A.H. Fielding (1989). Cell wall degrading enzymes of *Colletotrichum lindemuthianum*-Their role in the development of bean anthracnose. *Physiological and Molecular Plant Pathology,* **34**: 403–413.

Yadav, R.L., V. Singh, S.N. Srivastava, R.J. Lal, S.K. Awasthi and B.B. Joshi (2008). Use of *Trichoderma harzianum* for the control of red rot disease of sugarcane. *Sugarcane International,* **26**(4): 28-33.