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CHANGING DYNAMICS OF RED ROT EPIDEMICS IN SUGARCANE IN INDIA: TWELVE DECADES OF JOURNEY AND LESSONS LEARNT

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Dr C.A. Barber founder of ICAR-SBI, Coimbatore first reported red rot from the then Madras Presidency and laid a foundation on disease management in the country (Barber, 1901, 1906). During the same time, Dr. E.J. Butler, Imperial mycologist at the Imperial Agricultural Research Institute, Pusa, Bihar (India) conducted extensive studies of the disease on causative organism *Colletotrichum falcatum*, portals of entry into the cane stalk and named the disease as 'red rot' based on the most distinctive feature is the red-rot of internal stalk tissues (Butler, 1906). Both Barber and Butler recognized the importance of red rot and devised management strategies of healthy seed and avoidance of waterlogging to reduce the crop damage in India. Severe red rot epiphytotic in the Godavari delta and North Indian plains caused extensive damages to *Saccharum* spp clones of *S. officinarum* and *S. barberi*, however, this scenario resulted in the establishment of Sugarcane Breeding Institute (SBI) at Coimbatore, India in 1912 by Dr Barber to develop red rot resistant varieties through interspecific hybridization. Development of interspecific hybrids involving *S. officinarum* and *S. spontaneum* from Coimbatore starting from Co 205 in 1918 and hundreds of 'Co' varieties were released for commercial cultivation and adopted in India and in many other countries (Viswanathan, 2018, 2021a). Overall, red rot affected canes show a decline of 29 to 83% in cane weight and 24 to 90% in juice extraction. In the history of red rot epiphytotics in India, the country witnessed severe crop losses in each decade and currently it faces one of the worst crop losses due to sudden failure the most popular variety Co 0238 in the states of Uttar Pradesh and Bihar. The present scenario indicates nearly 10% of the cane area in the country has been affected by red rot hence the farmers and industry face the economic repercussions caused by the disease in the country. The lecture reviews the history of red rot epidemics occurred in the country, economic repercussions, origin of new pathotypes and pathogenic variation, varietal deployment and promising management strategies adopted in the field.

Red rot epiphytotics in hybrid varieties

From the first batch of hybridization programme, along with Co 205, the other varieties Co 210, Co 213 and Co 214 had become commercially popular in the subtropical region after 1920s. This effort was highly successful and made a



revolution in sugarcane agriculture in a short period. The commercial success of utilizing wild species to incorporate desirable genes gave a new direction to the contemporary and future sugarcane breeding programmes in almost all the sugarcane growing countries (Nair, 2011). However, after few years of its adoption, red rot infection caused a set back to the cv Co 205 in Punjab and Jammu. The cv Co 210 faced a severe red rot outbreak from total freedom from red rot for six years and in 1930s in Uttar Pradesh and Bihar. Due to ravages of red rot during that time, cultivation of a local thick *S. officinarum* (*Ponda*) had to be abandoned (Chona, 1954). During the 1938-39 season, a red rot epidemic of extraordinary severity occurred in the subtropical region particularly in UP and Bihar, the major sugarcane belt in the country. This havoc resulted in failure of the predominant commercial cv Co 213, in which thousands of hectares were devastated. Due to the poor supply of canes, the sugar mills in the eastern UP crushed only one third of their normal canes during 1938-39 and half in 1939-40 (Chona, 1941). About 70,000 ha reduction in cane area was witnessed during the epidemic and the severe epidemic had completely wiped out the cv Co 213 from cultivation in the major sugarcane track of the country and millers lost the popular variety that served them for nearly a decade. The cane area was supplied with huge quantity of seed of the cvs Co 299 and Co 331 to maintain sugarcane area in the region. In Bihar, due to severe epidemics, the cvs Co 313 and Co 513 replaced Co 213 in North and South Bihar, respectively. These new varieties survived only for 2 to 3 seasons and succumbed to the disease; again the cultivators faced grim of large scale red rot epidemics in the region in 1940s. Later, during 1946-47 red rot epidemic flared up again in the cv Co 312, popularly referred as '*Mamchuah*' in UP; this disease epidemic not only affected the crop in eastern UP and Bihar, it spread to central and western UP and Punjab. In the following years, red rot epidemics struck other popular varieties such as Co 301, Co 313, Co 385, Co 421, Co 453, BO 11 etc in northern Bihar and UP. After these epidemics, in Bihar, 'BO' varieties such as BO 3, BO 10, BO 14 and BO 17 replaced 'Co' varieties. Although red rot was reported in Punjab, Delhi and UP later during 1950s and 1960s the disease severity has been reduced to a moderate level by adoption of better varieties with red rot resistance (Viswanathan, 2021a). However, the cv Co 1148 which occupied ~55% of the area in the subtropical region succumbed to red rot during the late 1970s and Western UP and Haryana witnessed the epidemics during 1980-83 (Satyavir et al., 1984). The high sugar and early maturity cv CoJ 64 released for commercial cultivation in 1975 in Punjab rapidly spread to entire subtropical region had brought a sweet revolution in the region but it also succumbed to the disease in the late 1980s and its spread reduced in the region by 2000.

Re-emergence of red rot in the tropics

After the first report of red rot in 1901 by Barber in the east coast region, it was contained and no reports on severe disease incidences were made till 1960s. During 1958-59, the disease reappeared on the cvs Co 421 and Co 997 in West Godavari and



Vizianagaram districts. Later, the disease spread to entire coastal districts and devastated the ruling varieties Co 419, Co 997, Co 62175 and CoA 7701 due to the epidemics during 1960s and 1970s. During 1972, the disease struck for the first time in east coastal region of Tamil Nadu on the ruling variety Co 658. Apart from Co 658, red rot affected other varieties/ clones such as Co 449, Co 7504, Co 7507, Co 6315, N 65217 and N 67113 in the state. From then onwards red rot caused a rapid spread in the subsequent decades and has ruined many promising elite varieties such as CoC 671, CoC 8001, CoC 85061, CoC 86062, CoC 90063, CoC 91061, CoC 92061, CoC 98061, CoC 99061, CoC 24, CoSi 86071, CoSi 96071, CoSi 98071, CoSi 6, and TNAU Si 8 released from TNAU, varieties of ICAR-SBI, Co 6304, Co 87012, Co 91017, Co 92012, Co 94012, Co 95020, Co 99006, Co 0323 and Co 06022 and varieties from other states like CoV 94101, CoV 09356 and 89V74 (Viswanathan, 2017, Viswanathan et al., 1997, 2017a, Viswanathan and Samiyappan, 2000).

Emergence of hyper virulent pathotype in the tropics

The cv CoC 671, which set a benchmark in sugar recovery in the tropical states was released for commercial cultivation during 1975 and within a decade it spread to about 47% in Tamil Nadu and major areas in Karnataka, Andhra Pradesh, Maharashtra and Gujarat. Although the variety remained free from red rot for about a decade, the disease struck the newly released cvs CoC 8001 and CoC 86062 in 1986 and 1987, respectively in the state and the disease spread from these varieties to the major cv CoC 671 in 1987. During 1988-1990 severe epidemics caused huge destructions of the cvs CoC 671, CoC 85061 and CoSi 86071 in the coastal Tamil Nadu. As mentioned above, several varieties succumbed to red rot in 1990s and sugarcane cultivation had been plagued by the severe red rot in the entire state during this period (Alexander and Viswanathan, 1994). Detailed studies of Viswanathan et al. (1997) revealed emergence of highly virulent pathotype Cf671 (CoC 671) compared to those of Cf658, Cf6304 and Cf86062 isolated from the cvs Co 658, Co 6304 and CoC 86062, respectively. The new pathotype Cf671 with high virulence led to severe epidemics under field conditions, by which thousands of hectares were destroyed for about seven to eight years in 1990s (Viswanathan et al., 1997). In 1996, the state government banned cultivation of the cvs CoC 671 and CoC 92061 in order to contain the disease epidemics. Replacement of all the susceptible varieties with the cv Co 86032 brought down the impact caused by red rot in the state. Although the susceptible cv CoC 671 and other varieties were removed, continued cultivation other susceptible varieties harboured the pathogen after 2000 and this led to emergence of another virulent pathotype CF12 which was able to cause the disease in the cvs Co 2001-13, Co 06022, Co 06027, CoV 09356 etc that are rated as resistant to Cf671 (CF06) (Viswanathan, 2017, Viswanathan et al., 2020a).



Designating *C. falcatum* pathotypes

After the discovery of light isolates during 1930s and subsequent studies revealed existence of variability and appearance of several variants of the pathogen in the tropical and subtropical regions (Viswanathan et al., 2003). However, no differentials were established to identify the pathogenic variability and to characterize them. Studies of Padmanaban *et al.* (1996) have clearly identified the variants infecting the cvs Co 419, Co 997, Co 1148, Co 7717, CoC 671 and CoJ 64 into specific pathotypes based on differential reactions on a set of host differentials from hybrid varieties, *S. officinarum* (Baragua), *S. sinense* (Khakai) and *S. spontaneum* (SES 594). Afterwards *C. falcatum* pathotypes were designated as CF01 to CF02 and so far about 12 pathotypes were characterized (Viswanathan 2010, 2017). The pathotype(s) designated from each agroclimatic zones are used to screen the varieties in the zonal varietal trials. Currently, in the AICRP on Sugarcane, differential host interaction is being studied with 14 sugarcane differentials in both in subtropical and tropical regions. Recently more differentials were added to bring out further variation in *C. falcatum*. Current scenario in the subtropical region indicates emergence of new pathotype(s) that caused varietal breakdown on many popular varieties during the last 10 years. The new pathotype from Co 0238 has been found to be highly virulent and capable of knocking down most of the differentials. Overall, *C. falcatum* pathotypes exhibited enormous variation for pathogenicity in the field studies conducted in the tropical and subtropical locations simultaneously on a susceptible variety (Viswanathan et al., 2017a).

Evolution of virulent pathotypes of *C. falcatum*

The early red rot epidemics were confined to the thick noble cane varieties, whereas epidemics of the medium thick cane Co 213, had shown a new phase in the history of red rot epidemics in the country since the medium thick 'Co' canes and the indigenous *S. barberi* were considered as resistant. Occurrence of light coloured *C. falcatum* with highly sporulating phenotype was reported to cause severe devastation on the cv Co 213 during 1936-39 and this prompted the researchers to study on red rot pathogen. Successive failures of the cvs Co 331, Co 453, BO 11 and CoS 443 were attributed to the appearance of new virulent strains (Viswanathan, 2021a,b). Adaptive changes in *C. falcatum* have occurred in relation to the host varieties, with subsequent alterations in the virulence patterns of the pathogen (Srinivasan, 1965). The adapted cultures of the pathogen were able to tolerate the new cytoplasm which hitherto incompatible (Srinivasan 1962). Recently, a long term study conducted at the institute for 10 years revealed that the pathogen continuously making efforts to break the barriers of resistance more frequently in MS varieties and rarely on resistant ones and make them compatible for disease development. Hence, MS varieties exhibit red rot phenotypes of 'drying' from 'green' due to extensive colonization of the pathogen inside



the cane stalks by acquired virulence / adaptive changes of the pathogen (Viswanathan et al. 2020a).

It is reported earlier that in Indian scenario especially in the Indo-gangetic plains in UP and Bihar, red rot epiphytotics followed a 'boom' and 'bust' cycle in the last 100 years (Viswanathan, 2021a). Every time when the popular varieties were grown over large areas, the pathogen gained virulence substantially with something like super-virulent strains after failures of the varieties like Co 213, Co 312, Co 453, Co 1148, CoJ 64 in the previous century. Recently the popular variety Co 0238 was spread ruthlessly to entire command area that resulted in evolution of another super-virulent strain in the region. In the state of UP, the variety was grown in 2.2 M ha (82.21% of total cane area) and in Bihar 0.16 M ha (64.12% of total cane area) in 2019-20 cropping season (Ram, 2020). This monoculture of single variety over a large area has favoured evolution of highly aggressive strain of the pathogen (vertifolia effect) within three seasons. In this situation, the pathogen has evolved very quickly and caused varietal breakdown within a few years. First incidence of the disease was recorded during 2016-17 season in few districts and this historical epiphytotic destroyed nearly 0.5 M ha area in the current season, indicating a very rapid changes in the pathogen virulence. In the past, such gain of virulence was witnessed after severe epiphytotics in the cv CoC 671 in the tropical region (Viswanathan et al. 1997). Although emergence of highly aggressive strains of the pathogen has caused havoc in the country, the breeders have always undermined the pathogen onslaught by promoting single variety over several thousands of ha. Greedy sugar millers also spread the variety in an unscientific manner for a short term gain and finally end up losing to the pathogen. The loss is not ending here, due to the high virulence and aggression, the new pathotype causes varietal breakdown quickly and this poses a difficulty in finding replacement varieties. Hence, origin of new aggressive strains of the pathogen solely depends on the host side as suggested earlier (Srinivasan 1962).

Role of soil borne inoculum on varietal breakdown

Various hypotheses have been put forth to explain on how varietal breakdown occurs under waterlogged conditions and it was opined that predisposition of the host to infection under such condition is the major factor. Experience of various workers indicates that sugarcane varieties easily succumb to *C. falcatum* under waterlogged conditions and even the MR varieties cannot withstand against the onslaught of the pathogen (Viswanathan, 2010). On stagnant water, aggregation of floating mycelia occurs with production of conidia in acervuli. Further, the conidia germinate, fuse with each other, leading to aggregation of fused conidia. After fusion, some of the fused conidia germinate to produce conidia directly on them (Duttamajumder *et al.* 1990). Waterlogged condition may favour exchange of genetic material between variable isolates through heterokaryosis and possibly new variant in the pathogen population may originate under field conditions. Further, it is possible that



waterlogged condition prevails during the south west monsoon periods in the sub-tropical region and during northeast monsoon periods in east coastal region in the country, may favour origin of new pathogenic variants capable of knocking down existing variety in the field.

Although such phenomenon occurred regularly, how the varieties which were hitherto resistant to the pathogen succumb to the *C. falcatum* has not been comprehensively explained. Also longevity of resistance to red rot in sugarcane varieties has been unpredictable after their introduction to commercial cultivation. Recently, a detailed field study was conducted at the institute on how varietal breakdown occurs in the sugarcane varieties to red rot using soil borne inoculum sources and artificial inoculation by plug method (Viswanathan and Selvakumar, 2020). The varieties that vary in their reactions to *C. falcatum* did not show similar variation for their in behaviour in the plug method, whereas they exhibited a differential behaviour for the soil borne inocula in the field during three seasons (Viswanathan et al. 2020b). When the pathogenic behaviours in the two inoculation methods were compared, MR and HS varieties exhibited a similar phenotypic behaviour. However, four of the five MS varieties behaved differently to soil borne inoculum of *C. falcatum* pathotypes i.e., they tend to show very high levels of disease incidences even upto 100% as like susceptible varieties.

Under field conditions, *C. falcatum* exhibits enormous variation, when a new variety is introduced although it is initially incompatible it makes continuous effort to adopt to the new host variety and makes the incompatible to compatible in due course. Such a scenario was observed during the three years that the pathotypes with varied virulence somehow able to cause the disease in the MS varieties akin to their behaviour under endemic locations. Although the MS varieties succumbed to the pathogen under endemic locations they were not totally knocked down as in the case of susceptible varieties. This observation also revealed that the study mimicked the natural adaptation of the pathogen to the new varieties and causing varietal breakdown under simulated conditions. This study also clearly established certainty of field tolerance possessed by the ruling variety of the tropical region Co 86032 which survived in the region for more than two decades inspite of its continuous exposure to abundant inoculum in endemic locations (Viswanathan, 2018, 2021b). Although the variety has been in cultivation in large areas in different districts especially in the western region in Tamil Nadu as 'ES 353' and after its release by 2000 facilitated its spread to remaining parts of the state, Andhra Pradesh, Karnataka, Maharashtra, Gujarat, Madhya Pradesh and Odisha. The variety is occupying major area under cultivation in these states for the past 20 years and withstood red rot in different states and currently occupies more than 40% in these tropical states. The author also observed red rot in this variety during 2005, 2007, 2010 and 2015 in the region in few clumps in the fields and the pathogen could not make a headway in causing varietal breakdown as witnessed in the cases of CoC 671 and other varieties in the state.



Probably, the pathogen could not make adaptive changes in total hence breakdowns did not spread to large areas.

Conclusion

During the last decades of the 19th century, seeds of Indian sugar industry were sown by expanding sugar mill crushing capacities and also with installation of new sugar units in different parts especially in subtropical plains and east coast region. Since the industry needed high yielding varieties they imported many elite noble cane varieties to expand cane cultivation, mostly from Java and colonies of Great Britain. During that time the crop was struck with new disease problems and the most prominent was red rot and the disease severely affected cane cultivation in Madras Presidency and in Bengal. It is suspected that the disease was introduced through seed canes from Java. However, there are assumptions that the pathogen had prevailed in the country along with *desi* canes for centuries but attained severity with the new host varieties and expanded cane cultivation. Looking back on sugarcane cultivation in the country for about 12 decades, in spite of regular red rot epidemics during these decades there are gains for both the host and the pathogen. The disease remains a threat to cane cultivation in the country except Maharashtra and Karnataka states where many of the red rot susceptible varieties are being cultivated. These two states enjoy the benefit of cultivating many high sugar varieties in the field for many years, although they are susceptible to red rot. Apart from Co 86032, only a few susceptible varieties like Co 419, Co 740, CoC 671, Co 62175, Co 6304, Co 7219, Co 8371, Co 94012, CoM 0265 etc were grown during the last 80 years. Whereas other states witnessed frequent varietal replacements due to varietal breakdown to red rot hence benefit of many elite varieties could not be harnessed in the field. However, Maharashtra and Karnataka states faced problem of varietal degeneration in the cvs Co 419, Co 740, CoC 671 and Co 86032 due to mosaic, ratoon stunting (RSD) and YLD pathogens and prolonged cultivation of the varieties (Viswanathan 2001, 2016, Viswanathan and Balamuralikrishnan, 2005). As discussed earlier, the states where red rot occurs in epidemic form have confronted series of disease epidemics and many best varieties had a short field-life (Viswanathan, 2010, 2018, 2021a,b).

Hundreds of elite varieties developed at Coimbatore and other research centres in different states in the past decades were deployed for cultivation in red rot prone areas as varietal replacements that came with huge cost for the farmers and mills. The industries incurred huge losses during severe epidemics like those in Co 213 in the subtropics and CoC 671 in the tropics. On the positive side, determined efforts were made to replace the affected areas with new varieties through robust varietal development programme in India (Viswanathan, 2018, 2021a). This displays exceptional work done by the sugarcane researchers especially the breeding and pathology groups. The historical red rot epidemics of 1930s, 1940s, 1980s and present epidemics in UP and Bihar and epidemics of CoC 671 in the tropical states in 1990s



follow a path of boom and bust cycle and this reiterates avoidance of monoculture of a single variety in a large command area. Each and every boom and bust cycle has left a permanent mark on aggressiveness and heightened virulence of *C. falcatum* hence it is advised to adopt a mosaic pattern of varieties to combat the menace. New aggressive pathotypes with greater virulence cause strong erosion of host resistance and quick failure of new varieties. In the history, we found emergence of highly sporulating light type isolates with enhanced virulence over the earlier less virulent dark types.

Recently integrated management approaches developed at the Institute combine healthy seed, efficient sett treatment with fungicides by mechanized delivery, biocontrol with efficient antagonists and disease surveillance combined with varietal resistance show promises to manage the disease effectively (Malathi et al., 2017, Viswanathan and Malathi, 2019, Viswanathan et al., 2017b). During 1880 to 1930, the countries such as USA, Argentina, Australia, Brazil, Cuba, Indonesia, Mauritius, Puerto Rico and West Indies had witnessed severe red rot epidemics in sugarcane; however, currently they do not have serious disease threat (Viswanathan, 2010). These countries have successfully managed the threat through proper field sanitation and quarantine, whereas, India failed in this area and continue to battle with the menace for more than a century. Henceforth serious efforts are to be taken to eradicate all the susceptible varieties in the field even though their spread is in few pockets. Such pockets serve as reservoir for the pathogen inoculum leading to varietal breakdown in the new varieties. By adopting this integrated approach the country will harness the benefits from genetic gain achieved in many elite sugarcane varieties. Also disease surveillance has to be given due importance to take appropriate measures to contain the outbreaks immediately after its first report. Hiding the information and wrong advisories blow up the disease spread to large areas. Learning from the past mistakes will make better future for the farmers in the country.

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