Chapter 2

Survey, Incidence and Symptomatology

Introduction:

Sugarcane is responsible for 75% of the global sugar production and India is the largest consumer and second largest producer of sugar in the world. Indian sugar industry is the second largest agro based industry, next only to the textiles. But, being long durational crop, sugarcane is prone to the number of disease caused by pathogens viz. fungi, bacteria, viruses and phytoplasmas like organisms. Amongst all the diseases, red rot and smut are causing the major out-breaks in the recent years causing 30-100% yield loss in commercial sugarcane cultivars throughout India (Vishwanathan et al., 2003, Vishwanathan and Rao, 2011). Red rot disease is so devastating in nature that it has been referred to as cancer of sugarcane (Agnihotri, 1983). First time, red rot is observed in the cultivars of Red Mauritius in the Godavari delta of Andhra Pradesh (Barber, 1901). Outbreak in Co 419 and Co 658 in Andhra Pradesh, Tamil Nadu and Pondicherry indicated that those virulent races of pathogen have got their foothold in these areas. The quest for the new varieties has probably been responsible for the migration of the pathogen from one state to another. In India, red rot is chiefly the disease of standing cane and caused by Colletotrichum falcatum Went. 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 (Chona, 1954; Viswanathan and Samiyappan, 1999; Duttamajumder, 2002; Viswanathan, 2010). It is because the pathogen has gained virulence in last decade (Alexander and Jothi, 1995). Prevalence of variation in C. falcatum Went. (Perfect state:
Glomerella tucumanensis (Speg.) Arx and Muller) pathotypes is well known. The pathotypes exhibit distinct differential host interaction where certain pathotypes specifically infect their adapted host cultivars.

Red rot can affect many commercial varieties during its course of infection and epidemiology. Eventually, all the varieties fell prey to red rot and had to be withdrawn from the general cultivation or had to be replaced by the new more tolerant genotypes. The popular cane genotypes that served the Indian sugar industry succumbed to the onslaught of red rot and the list of such causalities is an ever increasing (Duttamajumder, 2008). Probably this is the reason that entire sugarcane breeding in India is geared up and focused around red rot resistance. More ever, this perpetual threat has taken a heavy toll on sugar production. Greater susceptibility of high sugar genotypes to red rot and wilt has deterred the cultivation of such genotypes on a large scale, and has forced the cultivation of more tolerant cane genotypes with moderate sugar, especially in subtropical belt in India.

The disease is the major constraint for sugarcane production of India and entire cane breeding in India is focused around this disease. The gaining importance of red rot is quite obvious by the fact that no sugarcane cultivar is released for cultivation without resistance to red rot (Duttamajumder, 2008; Viswanathan, 2010). The pathogen is mainly sett-borne (carried to the field through the planting material) and thus affect the crop from germination. The damage starts with germination failure, post emergence settling mortality to death of affected canes in later stages of crop growth. During germination phase, the pathogen causes symptoms of pre-germination death of buds and drying of germinated sprouts/shoots. In case of death of buds, symptoms of necrosis of buds and adjoining nodal tissues are seen. The root eyes will be discolored and rooting is arrested or it never happens. The pathogen can be readily isolated from the nodal region of such affected setts (Viswanathan, 2010).
Review of literature

The disease is distributed throughout the country (Plate 2.1). Besides, the disease is a regular threat of knocking down the important commercial cultivars in south India, in Uttar Pradesh the disease was noticed in CoJ 64 and Co1148 (2-10%) in Shahjahanpur and Saharanpur, up to 75% in CoPant 84211 and CoJ 84 in Sitapur, Lakhimpur- Kheri districts, CoS770 and CoS 802 in central UP, and up to 100% red rot on CoPant 84212 and CoJ 83 in Pallia and Lakhimpur-Kheri Districts (Viswanathan, 2010). In Bihar also red rot incidence was noticed in different locations. However, in many regions red rot in combination with wilt noticed in BO 70, BO74, BO 102, BO 120, Co 1148, CoLK 8001, CoS 687 and CoS 767. The disease has become a major threat to sugarcane cultivation in Punjab also. The varieties CoJ 64, CoJ 82 and CoJ 84 were infected to varying intensities from 1-80%. CoPant 84211 also recorded disease incidence up to 20%. The other varieties Co7717, Co 89003, CoJ 78, CoS 767, CoS 88230 and CoPant 84212 also showed red rot in certain location in Punjab (Singh et al., 2000; Anonymous, 2006). In Haryana, loss to sugarcane production was noticed in 8 sugar mills of 13 surveyed. However, 12 to 100 % incidence was recorded on sugarcane varieties viz., CoS 95422 and CoSe 98231 in most of the areas in Eastern Uttar Pradesh like Basti, Maharajganj, Kushinagar, Sardarnagar and Sant Kabirnagar (Anonymous, 2008).

Depending on the age of the stalk, time of infection and susceptibility of the cane genotype, it produces different types of symptoms. The typical stalk symptoms i.e., presence of white spots in otherwise rotten (dull red) internodal tissues and nodal rotting appear when the crop is at the flag end of the grand growth phase during August-September in subtropical India. In the early stages of infection, it is difficult to recognise the presence of the disease in the field, as the plant does not display any external symptom or distress. At a later stage, some discolouration 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 coloured 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 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 above ground symptoms appear. The type of symptoms varies depending on the prevailing weather conditions. At first, symptoms appear as the death of young and emerging shoots without any conspicuous identifiable symptom (in March-April-May in north Indian condition, spring planting). Occasionally spindle infection also appears with sporulation. However, in ratoon crop spindle infection appears much earlier. The dying symptoms are often confused with the damage of young shoots by rats/termites especially in ratoon crop (Duttamajumder, 2008).

Occasionally spindle infection showing heavy sporulation also appears in the emerging leaf (sett inoculation, adequate moisture). With the passage of time, if the infected shoot survive one encounter tiller mortality. This is just the extension of death of mother shoots due to primary infection. Thereafter, the spindle infection appears and its frequency is more during the onset of monsoon and gradually the frequency tapers. Spindle infection was also observed during the 1938-39 epidemic of red rot (Chona, 1942) and the epidemic of Godavari Delta (Barber, 1901), as evident from the furnished drawings and photographs of different symptoms.

Generally, infection traverses from the sett to the stalk without producing any conspicuous damage or reddening of the stalk tissues and finally reaches the crown where it expresses itself. On the way it may
occasionally express and damage the leaf sheath. Only one or two odd discoloured vascular bundles indicate the pith which *C. falcatus* followed during its passage through the immature stalk. On the crown leaf lamina, it also produces elongated lesion surrounded by yellow halo. In 3-4 days these water soaked lesions turn light brown and eventually become dark colour due to the bearing of abundant setae and spore masses (Duttamajumder, 2008).

Infected canes show drying of canes singly or in clumps. Initially the affected stalks show orange to yellow discoloration in top two to three leaf, which can be easily distinguished from the surroundings of green foliage (Viswanathan, 2010). Gradually entire foliage turns yellowish and dry. Foliage discoloration and drying take place in succession but it will be rapid i.e. in 2 to 3 days the discoloured leaves dry. It is not unusual to see sudden foliage discolouration in an apparently healthy crop under field conditions. Farmers are alarmed by such sudden disease development in a mature crop which is ready for harvest in a couple of week/months. Even though the disease development progresses gradually inside the canes, they remain green till a threshold of infection is achieved. Initially these symptoms are seen in few clumps distributed throughout the field and the intensity expands to diseased patches of dried canes later (Viswanathan, 2010).

Intensity of the disease in the field depends on many factors such as inoculum load in the planting material or soil, favorable weather conditions, variety, cultural practices being followed etc. Other than drying, no external symptoms will be seen on the infected stalks. Such foliage never shows any diagnosable symptoms. Similar to red rot, infection of wilt or infestation of root borer/grub in sugarcane also manifests such drying of clumps.

Usually infection of internal core tissues leads to expression of characteristic rind discolouration, which is normally dull red to brown. The rind discolouration is noticed on entire cane or it is confined to few
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internodes depending on the internal colonization of the pathogen. Typical nodal necrosis around the region of bud, growth ring and leaf scar can also be observed. Under favourable conditions, pinkish spore masses of the pathogen are seen on the nodal region, especially at root eyes exposing pinkish spore masses. Such visible pinkish sporulation can also be seen at rind tissues, growth rings and leaf scars. In some highly susceptible varieties after drying, the canes break off at nodes and show a de-topped appearance in the affected field. Close observation of such cane rind shows fruiting bodies of the fungus (acervuli) which may break through the rind surface especially from the root primordial or in the sunken cankers developed on the rind of affected stalks (Viswanathan, 2010).

The external symptoms of stalk rotting appear as discolouration of rind. At this time if the stalk is split open longitudinally, the typical red rot symptoms as described in the literature become visible in the internal tissues. Redding of the internal tissues interspersed with white patches (white spots), which are usually at right angle to the stalk axis, along with the presence of sourly alcoholic smell confirm the disease. Probably, these white spots in the internodal tissue of cane stalk act as the inn, where the pathogen safe guard itself from the host defences. The pathogen detoxifies the phenolic compounds from a portion of the cane tissues for comfortable stay in that area. In highly susceptible genotype, the border of white spot is indistinguishable with the back ground tissue, where as in moderately susceptible genotype the white spot when present in definitely surrounded by a dark red zone. Isolation from white spot area invariably yields virulent and sporulating form of C. falcatum. Infact, in the white spot area, tissue damage is most prominent and the tissues are usually devoid of cell contents and filled with air and web of fungal hyphae. When the stalk tissue with prominent white spots are allowed to dry, the white spot area become sunken, indicating greater moisture loss and tissue degradation of this particular area (Duttamajumder, 2008). The redness of the internal
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tissue of the cane is due to the phenolic compounds, which are invariably produced due to any type of injury/invasion.

Reddened or discolored vascular bundles run through the internodes in a characteristic manner in early symptoms (spindle infection). During the early phase of crop growth one or two odd discolored vascular bundles provide the quick transit route to the pathogen for reaching the crown. The fungal hyphae run along the vascular bundle, rarely venturing out in the parenchymatous tissues. At this time, no white spot or internal reddening, as seen in the typical symptom (August/September), develops and the pathogen hardly spreads sideways in the internode. In the late stage, when ambient temperature goes down, pathogen again restricts itself to the vascular bundles. However, the vascular bundles are definitely red and occasionally the pathogen ventures out in the surrounding intermodal tissues, sometimes giving the appearance of serial spotting (Duttamajumder, 2008).

The sourly alcoholic smell in the badly affected tissues is due to the preponderance of acetic acid bacteria that enjoy the hospitality of *C. falcatum*. With further progress of the disease, death of the cane takes place. It is important to note that sporulation usually appears after the death of the plant (formation of acervuli, the asexual fruiting structures). These appear externally on the root primordial and on the stomata present on the stalk and at any conceivable area where the pathogen finds or is able to create an exit point and internally in the cavities formed in the stalk (Duttamajumder, 2008).

The other important point that is quite characteristic of this disease is the rotting of the node. This nodal rotting also kills the bud and root primordial and renders the node unfit for germination and establishment. This typical nodal rotting helps to differentiate red rot from wilt, wherein the buds remain unaffected and retain viability. Moreover, it is the nodal tissue, in which the *C. falcatum* has to overcome first to establish itself in the standing cane (natural infection). Until and unless the pathogen
possesses the capability to damage the nodal region, it gets little chance to infect internodal tissues of the stalk in nature. In the nodal rotting, however, the vascular bundles running through the node remain largely unaffected, only the other connecting tissues are preferentially attacked. Sometimes in some cane genotypes, the cane breaks from the damaged node (growth ring) and topples the crown down. Through artificial inoculation, Duttamajumder and Mishra (2004) have shown that *C. falcatum* can enter through the immature internode via stomata present on the stalk. After the entry, it quickly reaches the node (up or below), growing along with the vascular bundles, just below the epidermis, without displaying any conspicuous symptom. In the nodal tissues, pathogen consolidates itself and then spreads to the new areas of the stalk. It has also been shown that through these portals *C. falcatum* invariably comes out and produces acervuli bearing conidia and setae on the surface of the stalk. Like many other members of *Colletotrichum* affecting different crops, *C. falcatum* hardly pushes away the epidermis of the stalk for the production of acervulus underneath; rather it takes the route of any available avenue, be it natural or artificial (Duttamajumder, 2008).

The other most important phase of the disease is the infection on leaf mid rib and leaf lamina. Typical midrib symptoms can be observation in most of the highly susceptible cultivars. Highly intensity of midrib lesions in the field is observed after summer rains and during monsoon months. The symptoms include elongated lesions on the midribs, reddish areas on the sheaths and infrequently small reddish brown spots on the leaf blades. On the midribs, the infected first appears as small reddish brown spots on the upper and lower surface (Viswanathan et al., 2011). These may expand rapidly in both directions and coalesce to form long lesions. The length of the lesions may vary from few inches to entire length of the leaf or they may remain as a series of unconnected lesions. In the beginning, the spots are bright red at first but later become straw colored in the centre with dark margins and frequently covered with black, powdery fruiting structures of
the fungus. If conditions are conducive, all the newly emerging leaves show midrib lesions. In severe cases the undifferentiated leaf tissues within the whorl slow lesions with rotting which results in death of growing point. Such symptoms can be seen during post monsoon month as discolorations in 3-4 top leaves with dead hearts (Viswanathan et al., 2011). Many disease resistant varieties also show reddish mid rib lesions of varying lengths. Such lesions will not be seen on lower surface of midrib. Usually *C. falcatum* is recoverable from the lesions of disease susceptible cultivars and in resistant cultivars association of *Alternaria* sp., *Curvularia* sp. and *Helminthosporium* sp.

In the early stages of infection, it is difficult to recognise the presence of the disease in the field as reddening of the internal tissues with interrupted red and white patches, the characteristic symptoms of the disease, develops on the stem only at later stages. Furthermore, latent infection occurs frequently, making visual diagnosis impossible. Consequently, planting of the infected sugarcane setts can spread the disease (Nithya et al., 2012). Specific red rot symptoms inside the stalk are reddening of internal tissues intercepted with white spots, which are usually elongated at right angles to the long axis of the stalk. The presence of the cross-wise white spots alternated with red spots is the characteristic diagnostic symptom of the disease. Infected canes also show the red discoloration throughout the length of the stalk with longitudinal cavities containing fungal mycelium. Later the affected tissues turn muddy, shrink and dry out (Viswanathan and Padmanaban, 2008). The disease occurs in various parts of the cane plant but is usually considered a stalk and seed piece disease. Its symptoms are highly variable depending upon the susceptibility of sugarcane variety and environment, but first appear as bright red lesions on the mid rib of the leaves, then drying of the leaves and ultimately the infected cane on splitting open displays reddening of internodal tissues and gives out alcoholic or acidic starchy odour due to fermentation although the fungus is not a true soil-borne organism; spores
washed into the soil may produce infection in planted seed pieces (Suman et al., 2005).

The white spots may vary in size and number and sometimes they are so numerous to give the tissue a mottled appearance. Further, infected cane may only give the tissue a mottled appearance. Further, infected cane may only show the red discoloration throughout the length of the stalk and tissue may sometimes turn a grey color in highly susceptible varieties. At later stages, affected cane loses its moisture content and by the time longitudinal cavities are prominent with grey mycelia of the pathogen or a clear liquid of pale or deep brown may develop. When mycelia appear inside, cane, the white spots become dull brown and overall, the internal tissue become, muddy and shrinks. In certain situations, presence of characteristic serial spots in the internode tissues can occur usually, in the upper internodes through which the pathogen reaches the meristematic tissues (Viswanathan, 2010).

Reddened vascular bundles pass through the infected regions, extending into the healthy tissues and frequently traversing the nodes into adjoining internodes. Similarly, pits of varying sizes and numbers are seen mostly along the centre of internode tissue. Varietal susceptibility, soil, moisture, atmospheric temperature and relative humidity influence expression of different symptoms such as number and size of white spots and pits. Infection of internal core tissues leads to expression of characteristic rind discoloration normally dull red to brown at varying intensities. Rampant colonization of the fungus inside the canes severely impairs sap movement and translocation of photosynthates to the roots. Hence, the affected cane dries out in course of time (Viswanathan, 2010).

Severe economic damages are caused due to red rot infection (tissue discoloration) by reduction in the stalk population and considerable reduction in sucrose content in infected stalks due to production of pathogen induced invertases (Viswanathan et al., 2009). It can reduce cane weight by up to 29% and loss in sugar recovery by 31% (Hussain and
Afghan, 2006). Severe losses due to red rot have been reported from many other countries including India (Khurana and Singh, 1975; Viswanathan and Samiyappan, 1999) and the subcontinent faced many epidemics in the past resulting in elimination of many popular varieties from cultivation (Viswanathan and Samiyappan, 2000). The epidemic of 1938-40 and 1992-96 in India were disastrous when the most widely grown varieties were wiped out of cultivation and the disease still remains to be serious concern. The sugar industry in India suffered losses more than 500 million US dollars every year due to red rot (Alexander and Viswanathan, 1996; Viswanathan and Samiyappan, 1999; Viswanathan et al., 2002). Hence management of red rot in sugarcane has become an important issue in all the sugarcane growing areas.

Combined infection of *C. falcatum* and wilt pathogen *Fusarium sacchari* is recorded in the field in India and in other countries. In such canes, progress of *C. falcatum* inside the cane is halted and the rotten tissues exhibit a purplish red color. The wilt pathogen immediately after its entry moves very fast through the infected internodes from the base, reaches unaffected internodes, and cause pithy cavities with pinkish discolored patches, which are characteristic to wilt (Viswanathan, 2010). Usually combined infection results fast drying of cane stalks as compared to their infections alone. Occasionally combined infection of red rot and wilt may also have infection of sett rot pathogen, *Ceratocystis paradoxa* in standing canes. Under field conditions, people fail to identify the disease correctly due to certain overlapping symptoms with other stalk disease of sugarcane like wilt, stalk rot and pineapple disease (Viswanathan, 2010).

In case post–germination infection, death of settlings occurs and affected plant shows yellow discoloration and drying of entire shoot with small leaves. Discoloration and drying symptoms are very common in the germinated settlings up to a month. In later stages, drying of whorl alone amidst healthy leaves is observed. These symptoms may mimic drying of central core tissues of early shoot borer infestation in
surrounded sugarcane. However, in case of borer infestation the affected whorl could be pulled out easily, whereas, in red rot affected plants the tissue did not come off. Moreover, insect attack resulted in complete rotting with blackish discoloration of internal tissues, emitting a foul odour. In contrast, in red rot affected tissues, the leaf sheath or whorl, tissues showed complete discoloration with continuous or discontinuous pathogenic lesions. Rotting or emittance of any specific odour was not associated with red rot in the settling stage infection. In case of whorl infection, the whorl tissues exposed outside were completely dried and usually straw colored. Occasionally circular lesions were seen serially on the dried whorl surface. Pathogen was readily isolated from such lesions (Viswanathan, 2010).

The number of infected stalks in any particular clump may vary in the field and distribution of severely diseased clumps in the field is rarely uniform. However, in the recent epidemics on CoC 671 and CoC 92061 in Tamil Nadu, Pondicherry, Karnataka and Gujarat complete crop drying in hundreds of hectares was noticed (Plate 2.1). In the ratoon crop, the field symptoms of the disease are similar to those in plant crop. Additionally a crop stand with crop-free patches is commonly seen as a result of germination failure in stubbles (Viswanathan, 2010).

Uttar Pradesh is a major sugarcane cultivating area in India with high potential of red rot threat because of maximum area under water logging conditions and favorable environmental condition for the spread of red rot. But not much study in the past has been done on newly available red rot isolates from the field’s canes. Since, the regular severe incidence of red rot disease has recorded in many important commercial cultivars of sugarcane in different parts of Uttar Pradesh, India; the present study was undertaken with the objectives to survey different sugarcane areas of Uttar Pradesh, India for natural incidence of the disease with symptomatology in different sugarcane commercial cultivars.
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Materials and Methods

Survey

An extensive survey of sugarcane growing areas of Eastern, Central and Western regions of Uttar Pradesh viz: Basti, Maharajganj, Kushinagar, Sardarnagar and Sant kabirnagar, Deoria, Gorakhpur, Khalilabad, Lucknow, Bareilly and Shahjahanpur were conducted during July and August months of 2007-2008 to 2008-2009, to study the incidence of red rot disease (clump basis) on six different commercial growing cultivars of sugarcane (CoSe 8436, CoS 91269, CoJ 64, CoSe 95422, CoSe 98231 and CoLk 8102) under natural field conditions at different locations. Symptoms of red rot disease on these cultivars were recorded.

Results

Incidence

During survey of sugarcane crops in different parts of UP, 100% incidence of red rot was recorded in variety CoSe 8436 at Shahjahanpur and Bareilly, variety CoLk 8102 at Basti and variety CoSe 95422 at Kushinagar respectively. Besides severe incidence of red rot ranging from 5-42 per cent was also recorded in west, central and eastern part of UP on CoS 8436, CoS 91269, CoJ 64, CoSe 95422, CoSe 92423 and CoLk 8102 sugarcane varieties (Table 2.1). The devastating spread and serious losses to the crop prompted us to characterize the associated isolates of red rot pathogen, to know the real cause of their spread so as to formulate the significant control measures.
Table 1: Survey and the incidences of red rot disease on commercial grown varieties of U.P

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Red rot isolates</th>
<th>Location</th>
<th>Varieties</th>
<th>Incidence of red rot*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cf-06</td>
<td>Shahjahanpur</td>
<td>CoS 8436</td>
<td>100%</td>
</tr>
<tr>
<td>2.</td>
<td>Cf-1B</td>
<td>Bareilly</td>
<td>CoS 8436</td>
<td>5-7%</td>
</tr>
<tr>
<td>3.</td>
<td>Cf-2B</td>
<td>Bareilly</td>
<td>CoS 8436</td>
<td>100%</td>
</tr>
<tr>
<td>4.</td>
<td>Cf-17</td>
<td>Karmaha</td>
<td>CoSe 95422</td>
<td>42%</td>
</tr>
<tr>
<td>5.</td>
<td>Cf-Kushinagar</td>
<td>Kushinagar</td>
<td>CoSe 95422</td>
<td>100%</td>
</tr>
<tr>
<td>6.</td>
<td>Cf-18</td>
<td>Bilari khash</td>
<td>CoS 91269</td>
<td>11%</td>
</tr>
<tr>
<td>7.</td>
<td>Cf-19</td>
<td>Devkaiya Futahva</td>
<td>CoJ 64</td>
<td>7%</td>
</tr>
<tr>
<td>8.</td>
<td>Cf-20</td>
<td>Sardar Nagar</td>
<td>CoSe 92423</td>
<td>22%</td>
</tr>
<tr>
<td>9.</td>
<td>Cf-01</td>
<td>Khalilabad</td>
<td>CoSe 92423</td>
<td>12%</td>
</tr>
<tr>
<td>10.</td>
<td>Cf-10</td>
<td>Basti</td>
<td>CoLk 8102</td>
<td>100%</td>
</tr>
</tbody>
</table>

* based on localized (limited) observation

Symptomatology

Different types of symptoms were recorded on different varieties at various surveyed locations. The most common symptom observed in red rot affected fields, was discoloration and yellowing of the young crown leaves (Plate 2.2-2.7). The discoloration and withering continued from the tip to the leaf base until the whole crown withered and the plant died within 10–15 days. As the disease advanced the entire stalk rotted and the central tissues became pithy. The internodal tissues were reddened throughout the basal portion, especially the vascular bundles, which were intensely red, with many cross wise white patches, interrupting the reddened tissues. The internodes shrunked in affected varieties and when such canes were splitted open, large cavities were found in the centre and the pithy tissues appeared reddish- brown with vinegar and alcoholic smell. Often a profuse whitish growth of the fungal mycelium was observed in the brown black grown of the host tissues. In some cases, black, minute, velvety bodies, representing
the acervuli of the fungus in the intermodal tissues were also seen. The sugarcane field of variety CoSe 8436 at Baheri, Bareilly and CoLk 8102 at Lucknow and CoSe 95422 in most of the areas in eastern Uttar Pradesh (Sardar Nagar, Basti, Maharajganj) was found severely affected with the disease. In some fields, 100% incidence was observed at Baheri (Bareilly), Basti and Maharajganj (Eastern UP) (Table 2.1).

The distinguished symptoms recorded on six different varieties during the present study have been reported herein:

**CoSe 95422**

During survey of sugarcane var. CoSe 95422 at Kushinagar and Karmaha (Gorakhpur) in the month June-July 2008-09, drying and yellowing of crown leaves alongwith drying of entire stalks were recorded (Plate 2.2a,b). After splitting open the dried cane reddening of inter nodal tissues without white spots (Plate 2.2c) and interrupted with white spots (Plate 2.2d) were clearly seen in the affected tissues. Nodes of the affected stalk were shrunken and white dirty mycelium was found in pith tissues of inter node. The whole affected field of sugarcane var. CoSe 95422 was dried at Kushinagar location (Plate 2.2a).

**CoS 8436**

During survey of sugarcane var. CoS 8436 at Shahjahanpur and two different locations at Bareilly, UP, the pathogen (C. falcatum) produced yellowing of crown leaves followed by drying of affected stalks (Plate 2.3a) during mid June to July, 2007-08. The internodal infected tissues had a dull red color interrupted by whitish patches all across the infected stalk at all the 3 different locations in var. CoS 8436 (Table 2.1, Plate 2.3b). More white spots were seen at the basal portion of the affected stalks in comparison to upper half (Plate 2.3c). The height and girth of cane stalks were severely decreased because of red rot infection. The range of disease incidence varied from 5-100% at three different locations in the present
study (Table 2.1). However 100 per cent incidence was recorded in fields of Bareilly and Shahjahanpur during the month of July 2008-09.

**CoJ 64**

Sugarcane var. CoJ 64 at Devkaliya Futahva (Gorakhpur) showed drying and yellowing of crown leaves with the red discoloration of intermodal tissues throughout the length of the stalk, and infected tissue turned a grey color during June-July, 2008-09 (Plate 2.4a,c). The affected stalk tissue also developed a characteristic, slightly acidic starchy odour and turn dull red interrupted by occasional whitish patches (Plate 2.4c). Often the entire sett was rotted and the tissues turned various shades of red, brown or grey. Dense wefts of dark grey, fluffy mycelia were seen in the pith cavities. Reddened vascular bundles also pass through to the healthy tissues on the upper portion of the affected stalks (Plate 2.4b). The entire affected stalks converted into dried cane stalks without juice and of no further use to mill supply.

**CoSe 92423**

The entire crown of sugarcane var. CoSe 92423 from Sardarnagar and Khalilabad (Gorakhpur) fields were found dried up at margins during the present study in the month of July-August, 2007-08 (Plate 2.5a). Later, the entire crown dried up and dropped (Plate 2.5a). The same variety substantiated by producing reddish and black patches appeared externally at intermodal surface (Plate 2.5b). On splitting, the internal tissue became pinkish with white transverse bands (Plate 2.5c). Infected tissues also emitted alcoholic sour smell. Emergence of orange reddish conidia was also seen on the shrunken nodes of variety at Khalilabad location. The affected stalks become hollow and pithy filled with fungal mycelia.

**CoSe 91269**

On the leaves, the pathogen produced elongate red lesions on the upper surface of the midribs. Var. CoSe 91269 at Bilari Khash (Gorakhpur). Up to 22 per cent incidence was recorded in the affected field
The affected fields included drying and dying of canes stalks. The split open affected stalks intermodal tissues showed reddish discoloration without white patches (Plate 2.6b). The stalks surface in affected fields looked shrunken dry with brown patches all along the intermodal surface (Plate 2.6c) with dried and fibrous nodes with dead eye buds.

**CoLk 8102**

The sugarcane variety CoLk 8102 at Basti found to have drying of cane stalks during June-July, 2007-08 (Plate 2.7a). After splitting open the canes, the infected tissues had a dull red color interrupted by occasional whitish patches across the stalk (Plate 2.7b). Affected internal tissues produced alcoholic foul smell. The affected stalks were found completely dried with hollow pith (Plate 2.7c).

**Discussion**

During survey of sugarcane crops in different parts of UP, the incidence of red rot was recorded up to 100% from Shahjahanpur (CoS 8436), Bareilly (CoS 8436) and Kushinagar (CoSe 95422). Different types of symptoms were recorded on different varieties at various surveyed locations. The most common symptoms observed in red rot affected fields was discoloration and yellowing of the young crown leaves followed by drying of entire stalks in the affected field. The internodal tissues were reddened throughout the basal portion, especially the vascular bundles, which were intensely red, with many cross wise white patches, interrupting the reddened tissues as described by earlier workers (Duttamajumder, 2008; Viswanathan, 2010). In most of the affected fields of red rot association of wilt disease was also observed. During the survey in the present study, the sugarcane filed of variety CoS 8436 at Baheri, Bareilly, CoLk 8102 at Lucknow and CoSe 95422 in most of the areas in Eastern Uttar Pradesh (Sardar Nagar, Basti, Maharajganj) was found 100 per cent affected with the disease. In these varieties 100% losses were estimated.
The red rot pathogen can infect seed pieces or cuttings, standing stalks, leaf sheath, lamina and midribs, but rotting of the stalk is of primary importance (Abbott and Hughes, 1961; Singh and Singh, 1989). On infection, whether due to seed borne inoculums or otherwise, the affected plants show some purplish discoloration on the external surface of the internodes near the point of infection. Later on, yellowing and drying of foliage are observed. However, classic diagnostic symptoms are observed when diseased canes are split longitudinally. In split stalks of susceptible varieties, internodal tissues show a red discoloration interrupted by whitish patches perpendicular to the axis of the stalk. These stalks emit a slightly acidic and starchy odour. The white patches or spots vary in size and appearance. Sometimes the affected tissues appear mottled. The nature of the white spots is also related to host resistance/susceptibility. In comparatively resistant varieties, the white spots are absent and only the central pith shows red streaks. The nodal tissues of infected stalks may rot and this is related to host reaction.

On the leaves, the pathogen produces elongated red spots on the upper surface of the midribs. They can remain small or elongate along the midrib. Initially, the spots are dark red, and then become straw-colored with purple margins that may be covered with small black flecks which are the fruiting bodies of the fungus (acervuli). In rare cases, the pathogen produces small dark red spots on the lamina. The pathogen also attacks leaf sheaths producing reddish patches.

Similar symptoms were also recorded by earlier workers on red rot affected varieties from India (Vishwanathan et al., 2003, 2010, Dattamajunder, 2008). The typical red rot symptoms i.e. presence of white spots in inter-nodal tissues and nodal rotting appeared when the crop is at the grand growth phase during August-September in all over Uttar Pradesh. 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 become
apparent when internal tissues have been badly damaged and are fully rotten. 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. The infected cane setts also carry the primary infection to the field. Depending on the nature of infection and availability of favorable 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 above ground symptoms appear (Singh and Singh, 1989; Viswanathan et al., 2003). Infected cane also showed the red discoloration throughout the length of the stalk with longitudinal cavities containing fungal mycelium. Later the affected tissues turn muddy, shrink and dry out.
Plate 2.1: Occurrence of red rot disease in India
Plate 2

Plate 2.2: a: Dried sugarcane field of variety CoSe 95422 at Kushinagar district, b: overview of sugarcane field affected with red rot disease showing yellowing and drying of top leaves of variety CoSe 95422 at Karmaha, Gorakhpur district, c: Reddening on intermodal tissue, d: reddening and browning of internodal tissues interrupted with white spots
Plate 3

Plate 2.3: a: Field view of sugarcane field of var. CoS 8436 at Shahjahnpur district showing yellowing of crown leaves and drying of infected stalks, b: Reddening on internodal tissue at basal portion in affected field of sugarcane variety CoS 8436 at Bareilly districts, c: reddening and browning of internodal tissues (lengthwise and breath wise) interrupted with white spots
Plate 2.4: **a**: Field view of sugarcane field of var. CoJ64 at Devkaliya Futahva (Gorakhpur) showing yellowing of crown leaves and drying of infected stalks, **b**: Reddened vascular bundles passed through to the healthy tissues on the upper portion of the affected stalks, **c**: reddening and browning of internodal tissues with irregular white spots on margins, nodal tissues were also completely dried and fibrous.
Plate 5

Plate 2.5: a: Field view of affected sugarcane variety CoSe 92423 at Khallilabad district of Uttar Pradesh showing yellowing of crown leaves followed by drying of entire stalks, b: Affected stalks showed shrunken surface with reddish and black patches, c: Pinkish reddening of internodal tissues with white spots, the affected stalks became hollow and pithy and filled with fungal mycelium.
Plate 2.6: a: Field view of affected sugarcane variety CoSe 91269 showing yellowing of crown leaves followed by drying of entire stalks, b: reddish discoloration of intermodal tissues without white spots, the internodes were pithy and fibrous without juice: c: Affected stalks showed shrunken blackish and brownish surface with dried nodes and eye buds.
Plate 7

Plate 2.7: a: Field view of affected sugarcane variety CoLk 8102 showing yellowing and drying of cane stalks, b: reddish discoloration of internodal tissues interrupted with varying numbers of white spots, c: the affected dried stalk with hollow fibrous piths.
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References


against red rot caused by *Colletotrichum falcatum*. *Indian Phytopathology*, 57, pp.24-29.


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